7. Characterization of PM and Nutrient (N & P) Sources

In addition to estimating the mass of nutrients and PM being deposited from the atmosphere to the surface of Lake Tahoe, staff investigated sources of air pollutant emissions in the Lake Tahoe Air Basin. Three approaches to source characterization are utilized and described in this chapter. The first is review of the existing emissions inventory for the California portion of the Lake Tahoe Air Basin to provide a broad overview of the sources in the Basin. The second is a summary of observations from limited, focused special studies undertaken in the context of LTADS to better characterize road dust emissions and wood smoke from fireplaces and stoves used for residential heating. The third is a review and analyses of the historical record of pollutant concentrations and meteorological conditions. Although inferential, we consider this to be the primary source of information about the relative impacts of sources on ambient concentrations and deposition.

Diverse types of data and analyses have the potential to improve understanding of the emissions sources that contribute to ambient atmospheric concentrations in the Tahoe Basin and deposition to the Lake surface. Those utilized include the current emissions inventory, the LTADS network observations, limited source-oriented monitoring, and focused studies designed specifically to improve the Tahoe inventory of motor vehicle and wood combustion emissions, and an extensive historical record of concentrations and meteorological observations. Although considered initially as a means to identify the relative contribution of various source types to ambient concentrations, application of a Chemical Mass Balance (CMB) was not pursued due to the limited resources available and the complexity of the analysis (e.g., variable source speciation profiles, measurement uncertainties associated with low ambient concentrations, and concentration measurement periods varying from one day to three weeks).

Although the LTADS monitoring network was designed mainly to support the primary study goal, that of quantification of atmospheric deposition of nitrogen, phosphorus, and particles to the Lake, it also provides information useful for understanding source-receptor relationships. The historical record of ambient concentrations was also supplemented with several short term local “dust experiments” (described in Chapter 4). Although these were designed to provide insights regarding temporal and spatial gradients in particle concentrations in between the monitoring sites, roads, shoreline, and offshore locations, they are also useful for inferring relative contributions from specific source types to deposition to Lake Tahoe. To improve specific aspects of the Tahoe emission inventory, focused limited field studies were conducted to better quantify emissions from wood combustion and motor vehicle operation. All of these observations, when examined in the light of temporal patterns of local emissions activity data and concurrent meteorological observations, provide inferential evidence about the relative impacts attributable to a specific emissions sources (e.g., nearest roadway) as compared to the cumulative impacts from other sources. The historical record of observed ambient concentrations provides some insights as to the relative importance

of emissions sources. Extensive analyses and conclusions drawn from these data form the final section of this chapter.

Staff consulted the current emission inventories for California and the Lake Tahoe Basin and used simple data analyses based on observed concentrations and meteorological conditions to identify the most pertinent pollutant source categories. The conclusions and results indicate the nature of the atmospheric deposition problem and suggest where control efforts could be directed to reduce the atmospheric loading to Lake Tahoe.

7.1 Existing Emission Inventory

Emission inventories quantify all known emission source types within the boundaries of a defined region. However, without air quality or dispersion modeling, they are not directly applicable for apportioning source contributions to ambient concentrations and neither are they applicable for apportioning deposition. The emissions are not directly related to observed concentrations because they do not include consideration of source-receptor relationships controlled by winds and mixing. Neither do they account for chemical transformations. Nevertheless, they do provide a great deal of perspective on the types of sources that may be important to both concentrations and deposition.

The emission inventory for the Lake Tahoe Air Basin has not been refined to support regulatory activity because the Basin currently meets the federal air quality standards. The inventory utilizes methodologies that are applicable statewide and thus it is not as closely linked to local information and conditions as it would be if it were required to support current regulatory actions. An additional limitation is that an emissions inventory for the Nevada portion of the Basin is not included in the CARB estimate, which is limited to the California portion of the Basin (~two-thirds of the total). To provide context, this review includes comparisons with inventories of emissions in surrounding areas.

For inventory purposes, emissions are quantified from emissions “activity” data, emission factors (profiles), and emission rates derived from results of representative source testing (e.g., grams of NO emitted per mile traveled by a particular vehicle type and model year operated in a specified manner to represent typical real world operation). Activity data for motor vehicle emissions could be hourly estimates of vehicle miles traveled by vehicle type, model and year, and road type. Similarly, activity data for a manufacturing or distribution facility might be the hours of operation and a throughput number (e.g., units manufactured per month, or gallons of fuel sold per month.) Other types of activity data (e.g., wood combustion per hour or month) might be estimated from a combination of population, percentage of dwelling units with fireplaces or wood stoves, and air temperature. The linkages between activity data, emission factors (profiles), and emission rates are based upon established procedures that are grounded in surveys and historical source test data from representative examples of the same source type.

Inventories for different pollutants vary in their level of accuracy with the information available for a particular region or source type. Evaporative emissions from individual vehicles are measured by enclosure of those vehicles in a chamber subjected to a prescribed range of temperatures. Tail pipe emissions (e.g., NO and NO_2) from individual vehicles are measured while the vehicles are operated under prescribed speeds and loads on a dynamometer. Information from testing of individual vehicles is extrapolated through the use of various models to quantify the emissions of an entire fleet of vehicles. Models incorporate information and assumptions about the representativeness of vehicle models and age, mechanical condition, and their operating conditions (e.g., driving speeds and distances, and environmental temperatures).

The mass of road dust lofted by passage of motor vehicles is much more difficult to estimate than motor vehicle tail pipe or evaporative emissions. First, not being confined within a well defined space, indirect emissions of road dust from motor vehicle activity are far more difficult to source test. Second, defining representative conditions for testing is complicated because the emission rates are highly dependent on highly variable environmental factors (e.g., amount and type of dust on the roadway) and vehicle characteristics (e.g., vehicle speed, aerodynamics, tire size).

Thus, assembling a complete inventory that quantifies all known sources of emissions requires extrapolation from available information. The accuracy of the inventory is related to the linkages assumed, the degree of representativeness of source test conditions and activity data, and the amount of extrapolation required. For example, motor vehicle emission estimates may be based upon source testing conducted near sea level extrapolated to another altitude. Estimates of road dust emissions made based on tests in one area with a particular soil type will likely differ from those actually occurring in another region. Wood use for home heating in one area may be estimated based upon surveys of wood use in another area.

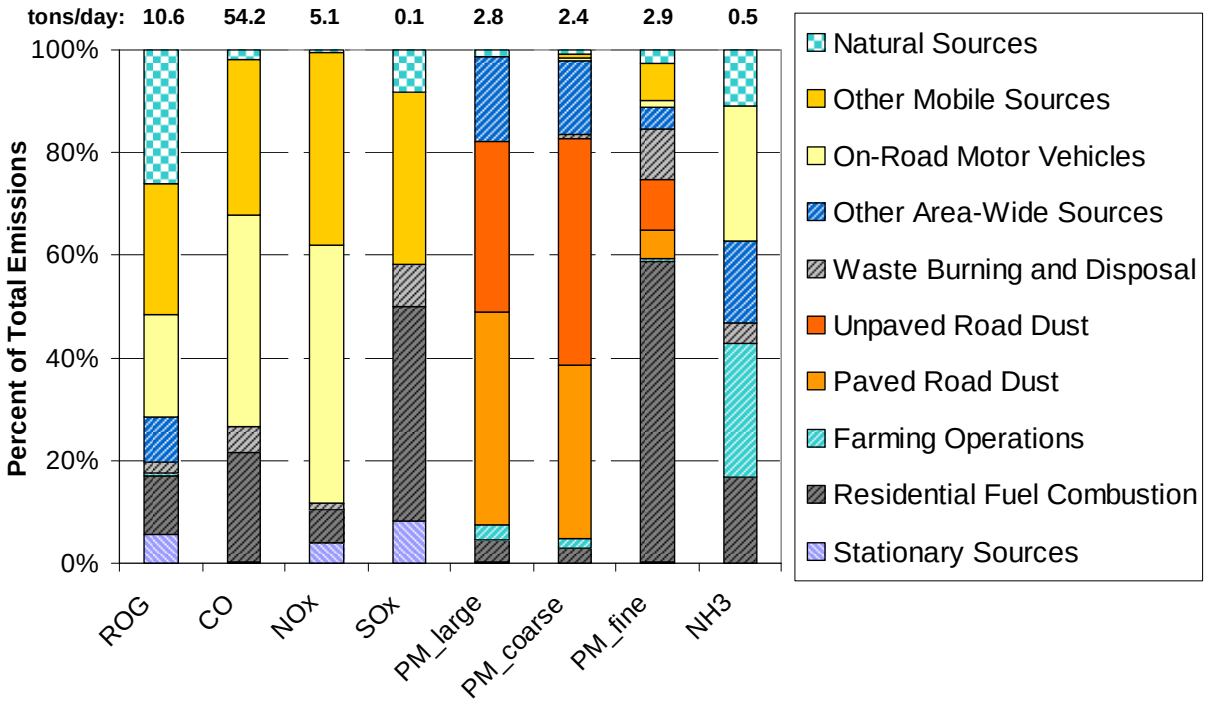
7.1.1 Lake Tahoe Emission Inventory

A summary overview of the Lake Tahoe Basin emission inventory is provided in **Figure 7-1**. For each of eight pollutant species, **Figure 7-1** lists the total emissions (tons/day) from sources within the Basin and breaks out the percentage of those emissions from each of 10 source categories. As in many other air basins, mobile sources are a major source category for reactive organic gases (ROG), carbon monoxide (CO), and oxides of nitrogen (NO_X), NH_3, and PM. Wood smoke from residential fuels combustion comprises the bulk of the PM_fine emissions.

As discussed in Chapters 3 and 4, NH_3 was found to be the primary component of N deposition to Lake Tahoe. Source categories that emit a significant percentage of the NH_3 include farming operations (that would include golf courses), on-road motor vehicles, waste burning (e.g., prescribed burns), and to a lesser extent residential wood burning. Nitric acid, which is a product of photochemical reactions that start with NO_x is another important chemical species with respect to nitrogen deposition. The main sources of NO_x are on-road motor vehicles and other mobile sources.

Direct emissions from on-road motor vehicles are indicated in yellow while direct emissions from other mobile sources are indicated in gold. Paved and unpaved road dust emissions, shown in orange and red respectively, are the major source categories for PM_coarse and PM_large.

Figure 7-1. Estimated emissions in the Lake Tahoe Air Basin for 2004 by source category. (CARB, 2005)



7.1.2 Comparison of Inventories in Neighboring Air Basins

A comparison between emissions from Lake Tahoe Air Basin and other air basins could be made with either the basin-wide mass emissions rates (mass/time) or the emissions densities (mass/time/area) for each of the air basins. In **Figure 7-2**, the graphical comparison of the mass emissions rates (mass/time) provided in the upper panel visually exaggerates the impacts from those air basins with larger areas. The emissions densities (mass/time/area) shown in the lower panel are more closely related to impacts on ambient concentrations and thus they provide a more meaningful basis for comparison of emissions between regions. When examined on the basis of their density, the Tahoe Basin's emissions for ROG, CO, and NO_X exceed those of Mountain Counties Air Basin but are much lower than those of the other neighboring air basins or regions.

Figure 7-3 shows the relative contributions of various source categories to the emissions of specific pollutants within central California that potentially affect the air

quality in the Tahoe basin (i.e., the region upwind and including the Lake Tahoe Air Basin). Contrasting with **Figure 7-1**, which shows the source contributions only within the Tahoe Air Basin, residential fuel combustion is a major source of fine particulate matter within the Tahoe basin.

Ammonia emissions (mass per time) by source category are contrasted for several air basins in **Figure 7-4**, but note that, for the reasons discussed below, the relative emissions do not indicate relative impacts. Clearly the ammonia emissions in the San Joaquin Valley (SJV) are substantial, but most of the area of the SJV is far south of Lake Tahoe. Similarly most of the Sacramento Valley is well north of Lake Tahoe. In addition, marine air that enters the central valleys through the Bay Area and delta and other gaps and lower passes in the coast range generally splits to follow the regional terrain. Typical flow is from north to south in the SJV and from south to north up the Sacramento Valley. Impacts affecting Lake Tahoe from emissions in upwind areas would also be limited to periods with sufficient vertical mixing as was discussed in Chapter 2. Thus, although **Figure 7-4** compares the mass of ammonia emissions estimated for 2004 in the Lake Tahoe Air Basin and nearby air basins, for the reasons discussed above, the amounts do not necessarily imply relative impacts on Lake Tahoe. Finally, the use here of emissions mass (tons/day) data instead of emissions density (tons/day/area) data for comparison purposes overstates the relative emissions due to the larger area of the SJV Air Basin.

The air basins differ substantially in their relative contributions of ammonia emissions from the various source types, as shown in **Figure 7-5**. Note that in the Lake Tahoe Air Basin the three largest source categories for ammonia emissions are motor vehicles, “farming” operations, and residential fuel combustion. These three source categories are estimated to account for 70 percent of the local ammonia emissions. These estimates of the contributions to total local ammonia emissions are consistent with the observed spatial variations in concentrations. Note that the greatest ammonia concentrations were observed in the more densely populated areas and at sites closest to roadways. Conversely, more spatially uniform ammonia concentrations than were observed during LTADS might be expected if there were substantial transport from other regions,

7.1.3 Historical Trends in Emission Rates at Tahoe

The estimated historical and forecasted future air pollution emissions for the California portion of the Lake Tahoe Air Basin are shown in **Figure 7-6**. From a long term perspective, emissions of both CO and ROG have declined substantially. Estimated emissions of NO_X have also declined but more slowly. Emissions of PM10 are estimated to be increasing. LTADS occurred during a projected stable period with respect to variations in emission amounts, with only CO and NO_X emissions declining.

Simple analyses relating concentrations and meteorology have the potential to provide strong corroborative information regarding the relative importance of different source types, both to the basin as a whole and to specific receptor locations. In an area as geographically unique as the Lake Tahoe Basin and having significant gradients in

emissions densities and spatially variable meteorology due to complex terrain, such corroborative analyses are an important means of confirming the relative impacts of source types. Such studies generally include spatially and temporally resolved emissions activity data, and observations of both ambient concentrations and meteorology.

7.2 Summary of Prior Analysis of Historical Aerosol Data

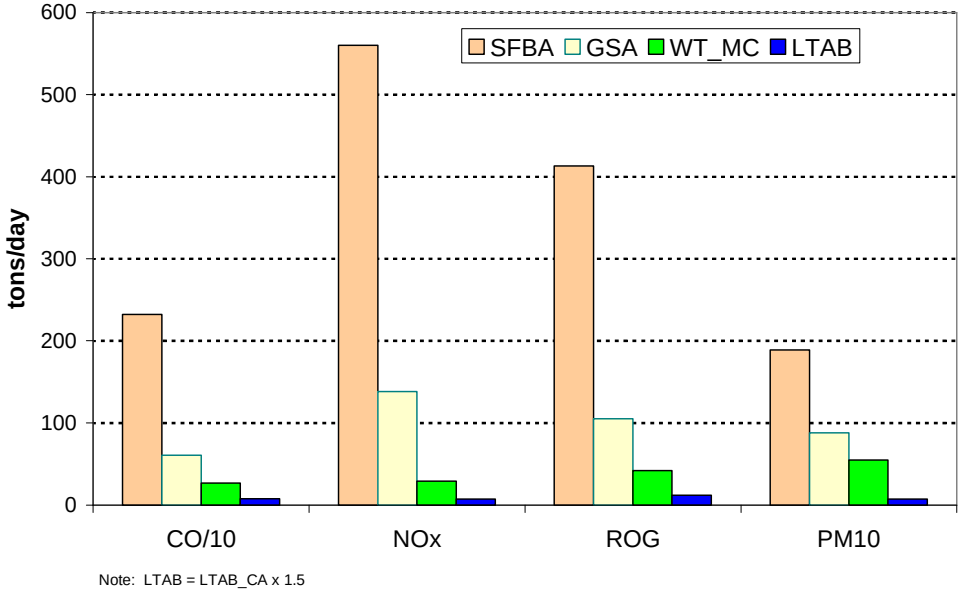
The data presented In Appendix B (Analysis of Historical Aerosol Data) show that the Lake Tahoe Basin is somewhat cleaner than the upwind lowland areas of California, but that it has considerably higher aerosol loading than non-urban sites in the Sierra-Cascade mountain chain.

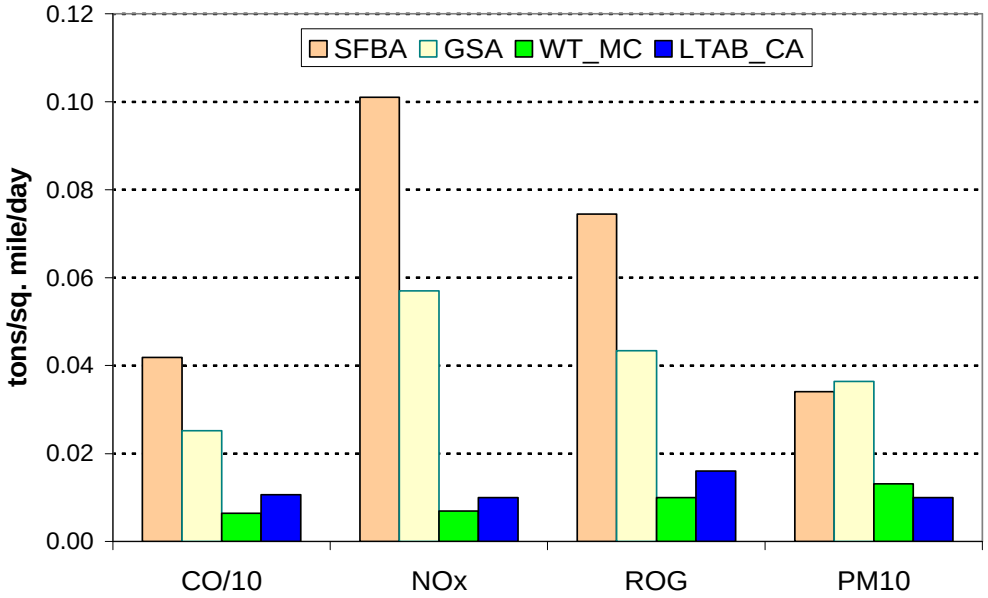
Analysis of the data collected in the Tahoe Basin shows that local sources dominate for smoke and road dust, but are less significant for typical secondary urban/industrial pollutants such as sulfate.

Transport into the Tahoe Basin comes primarily from the tropospheric “background”, which consists of continental aerosols derived from Asia. This source is ubiquitous in the higher elevations of Sierra-Cascade range, and provides a small (on average 4½ $\mu g/m^3$) baseline aerosol concentration wholly outside the influence of activities anywhere in California (VanCuren, 2003). Transported aerosols originating within California appear to contribute, on average, about 2½ $\mu g/m^3$ (VanCuren, 2003). Fires outside the Tahoe Basin occasionally deliver large amounts of smoke to the basin, but they appear to have minimal impact on average aerosol loading.

Further study is needed to determine the spatial distribution of pollutants within the basin; the data from the Bliss and South Lake Tahoe monitoring sites probably represent the extremes of pollutant concentrations in the basin.

Figure 7-2. Comparison of total emissions (upper panel) and emissions densities (lower panel) for the San Francisco Bay Area Air Basin, the Greater Sacramento Area, and the counties of the Mountain Counties Air Basin located to the west of Lake Tahoe, and for the Tahoe Basin, estimated for 2004. (CARB, 2005)





Notes: LTAB – Lake Tahoe Air Basin; analysis assumed that total emissions in LTAB = LTAB_CA times 1.5 to account for emissions in Nevada portion of the air basin.

SFBA – San Francisco Bay Area Air Basin.

GSA – Greater Sacramento Area (portions of Placer, Sacramento, and Yolo Counties in the Sacramento Valley Air Basin).

WT_MC – counties in Mountain Counties Air Basin that are located west of Lake Tahoe (Amador, El Dorado, Nevada, and Placer Counties).

CO/10 – the CO emission estimates have been divided by 10 to facilitate plotting on the same figure as the other emission types.

Figure 7-3. Estimated 2004 emissions by source category for combined area of SFBA, GSA, WT_MC, and LTAB. Contrast with Figure 7-1 for the LTAB only. (CARB, 2005)

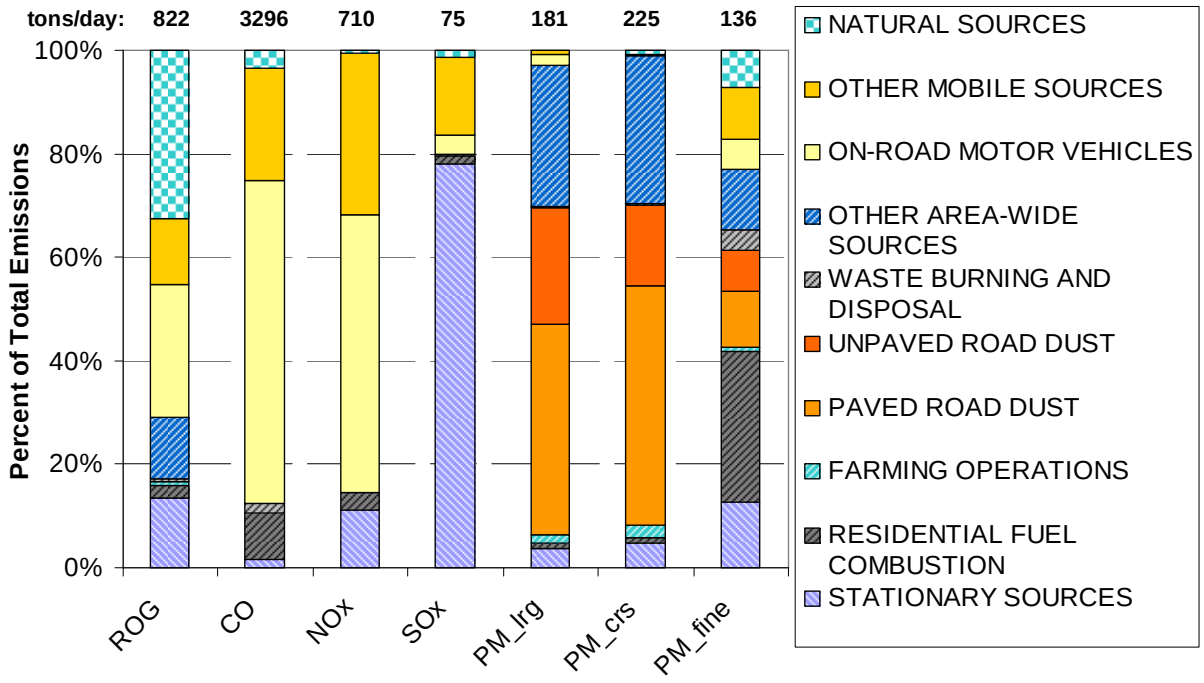


Figure 7-4. Comparison of ammonia emissions in Lake Tahoe, Mountain Counties, Sacramento Valley, and San Joaquin Valley Air Basins, for 2004. (Gaffney, 2004**)**

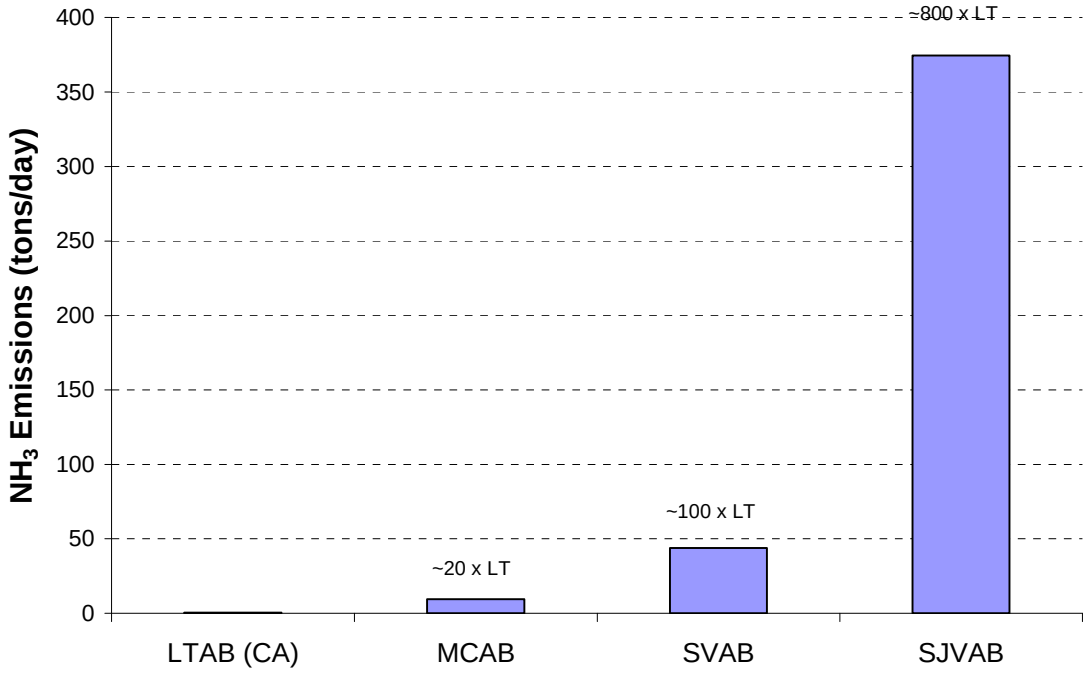


Figure 7-5. Percent of ammonia emissions by source category in the Lake Tahoe, Mountain Counties, Sacramento Valley, and San Joaquin Valley Air Basins as estimated for 2004. (Gaffney, 2004)

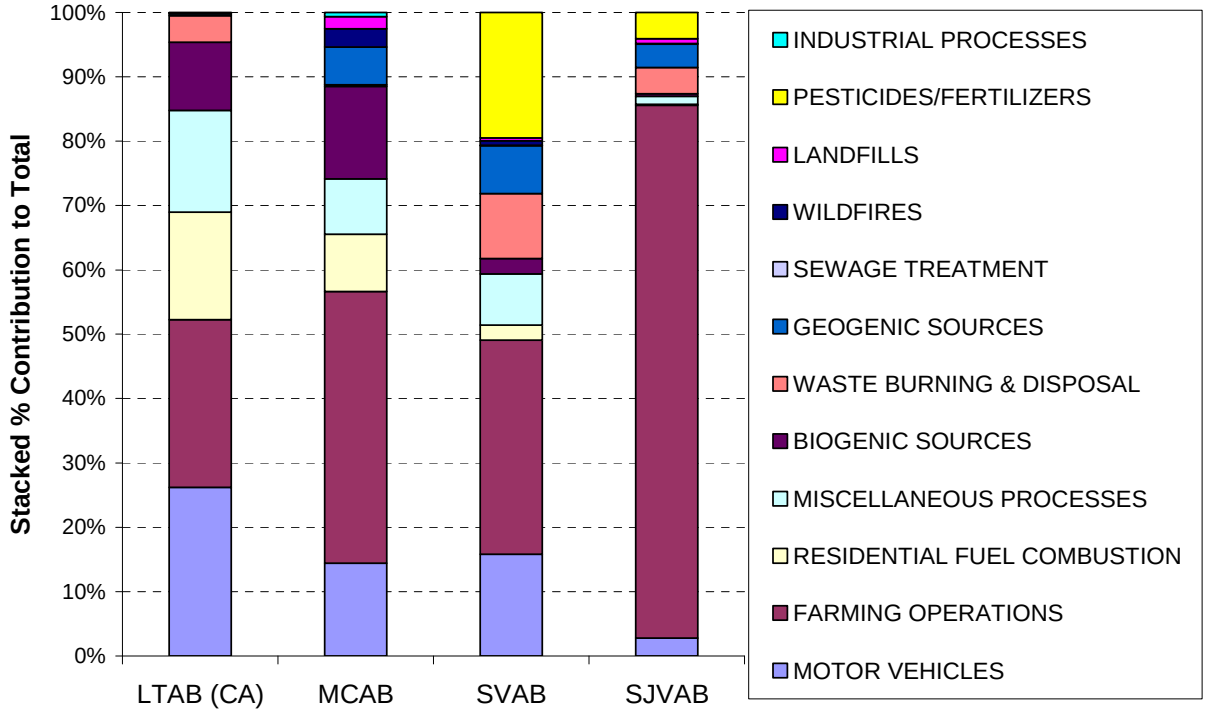
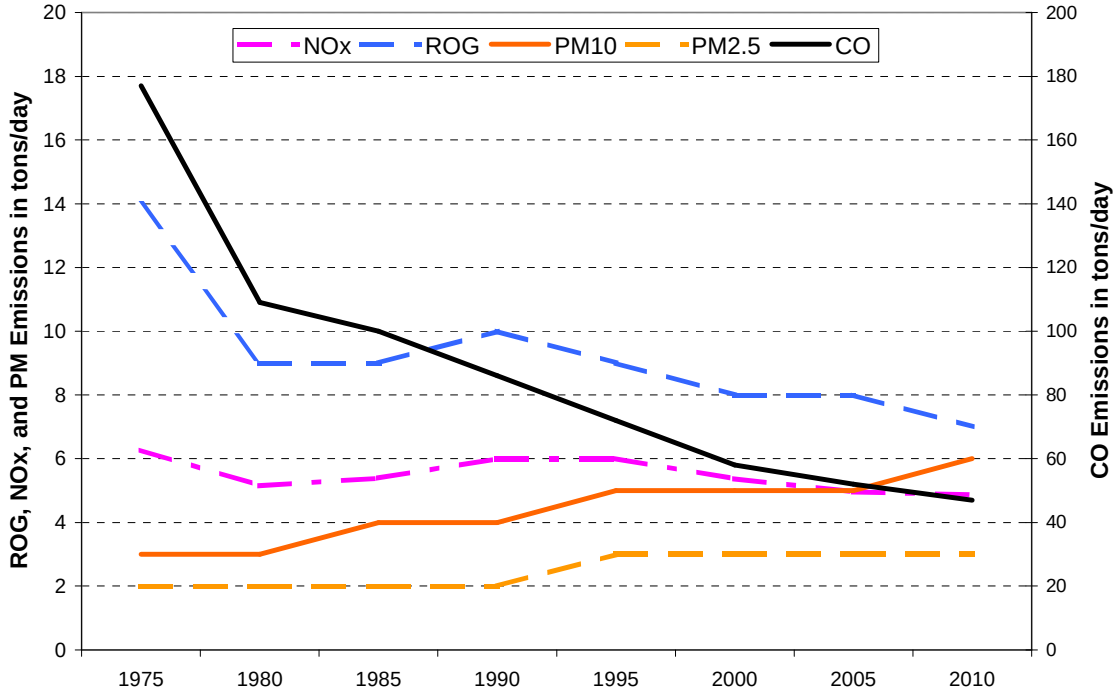


Figure 7-6. Historical and forecasted air pollution emission estimates for the California portion of the Lake Tahoe Air Basin. (CARB, 2005)



7.3 LTADS Studies to Improve the Tahoe Emissions Inventory

Unique challenges to constructing an emission inventory for the Lake Tahoe Air Basin include such things as differences between California and Nevada vehicle requirements, fuels, and air quality regulations, seasonally variable populations of residents and visitors, and alpine conditions not generally addressed in a statewide emissions estimation methodologies. The efforts undertaken were limited and narrowly focused to provide information that could be applied to improve the inventory with respect to estimates of emissions of road dust from motor vehicle operations and smoke from wood combustion.

The study approaches and results are summarized in this section. Insights from these special studies are also leveraged with results from the dust experiments (described in Chapter 3) that were designed to provide insights as to temporal and spatial variations in PM concentrations.

The unique situation at Lake Tahoe makes extrapolation of emissions activity data and emission factors developed in other areas problematic. Within an alpine environment there is a substantial population of permanent residents and a highly variable number of visitors. For estimation of motor vehicle emissions this presents several challenges. Nearly all CA vehicle source testing is conducted near sea level where oxygen vapor pressure is higher and ambient temperatures are constrained within a much smaller daily range than at Tahoe. Additionally, fleet characteristics are more difficult to specify with certainty due to differences between California and Nevada requirements for vehicles, registration, smog inspection requirements, and fuels. Additionally, fleet characteristics may change significantly with season or day of week due to the large visitor population and any weather related choices in vehicles or driving habits.

This section describes findings from the source characterization studies conducted for LTADS and also describes some limited analyses that aid in understanding the connections between emission activity patterns and ambient concentrations. The source types addressed here are road dust, motor vehicle emissions, and wood smoke.

7.3.1 Road Dust Observations

Road dust is a combination of traction control material, brake and tire wear, vegetative debris, deposited exhaust, and track out soil from unpaved roads (Kuhns, et al. 2004). Re-suspended road dust is associated with traction control material applied to the streets during winter. Wind blown dust occurs primarily in late summer during high-wind events when the soil moisture is at a minimum. Chemical analyses of road surface material indicate that most of the particulate matter is composed of crustal species (e.g., oxides of Al, Si, Ca, Fe, and Ti) (Watson et al, 1998; Chow et al., 2004). Connections between vehicle traffic activity and downwind PM ambient concentrations, nitrogen and phosphorus species concentrations within the activity-related plumes, and the content of fine (PM2.5) particles were the key areas of inquiry for the road dust part of the Desert Research Institute project (Kuhns, et al. 2004).

Connections between vehicle traffic activity and downwind PM ambient concentrations were investigated by DRI staff at a site near Sand Harbor. Sand Harbor is a park and beach area south of LTADS Thunderbird site. Sand Harbor is to the west of Highway 28 and the downwind site was to the east of the highway. The flux tower measurements were based on an up-wind/down-wind technique that has been often used by other investigators (Gillies et al., 1999). The DustTraks instrument and associated interpretive techniques are developing staples of motor vehicle source characterization studies (Kuhns et al., 2004).

Dust experiments provided evidence of the connection between vehicle activity and particle counts and also showed that particle counts and concentrations declined rapidly with distance from the roadway. Observed concentrations immediately downwind of the roadway also decreased rapidly with height above ground level (agl). As shown in the upper panel of **Figure 7-7**, concentrations decreased by over 50 % at 3 meters agl as compared to 1 meter agl. Although it was not feasible to make concentration measurements above the plume, the available measurements suggest that the plume height is likely no more than 4 to 6 meters. Because the depth of the plume is so limited, concentrations will decline rapidly with distance downwind due to dispersion and deposition.

In the lower panel of **Figure 7-7** the flux of PM10 is clearly seen to respond to wind direction, illustrating the strong effect of motor vehicle activity on the nearby PM10 concentrations as expected due to lofting of road dust. This is consistent with the observed downwind decay of particle counts obtained with OPCs, as reported in Chapter 4. Recall that as roadway emissions moved downwind toward the Lake under off-shore winds, particle counts obtained with the OPCs declined quickly. Similarly, particle counts were lower over the Lake than on shore. Thus, PM mass concentrations must also decline with increasing distance from the roads and distance from the shoreline.

The LTADS monitoring sites were necessarily located in the vicinity of roadways because the purpose of the LTADS (quantification of deposition to the Lake surface) required observation of concentrations near the Lake shore and that is also where population and human activity are greatest. Thus, the role of road dust in deposition to the surface of the Lake may be accentuated by the proximity to the shoreline of roads with high traffic volume. In fact, some of the roads with highest activity levels are on the immediate periphery of the lake. Thus, it appears that road dust is a major source of PM concentrations near the Lake shore and a major source of PM deposition to the Lake surface.

However, the distance of sources from the Lake is an important factor and measurements near sources will provide a conservatively large estimate of concentrations at the shoreline of the Lake and an even more conservative estimate of concentrations over the Lake. If refinement of the current estimates of PM deposition is a priority, then additional characterization of offshore gradients in concentration would be recommended as the first improvement upon the current estimates.

In order to better understand the composition of road dust, as differentiated from the combination of road dust and direct emissions from motor vehicles, additional measurements were made. DRI staff vacuumed road dust from sites around Incline Village, Village Lakeshore, and Mays/Southwood and proceeded to re-suspend the dust in a small chamber. DRI staff then sampled the "re-suspended road dust" for LTADS standard chemical analyses. Although the resulting filter samples contained substantial mass of vacuumed road dust, the laboratory results showed non-detects and low concentrations for nitrate, ammonium, and phosphorus. Concentrations of ammonium ion are at best 0.2% of the road dust mass.

The analyses of these samples of road dust provided a basis for relating observed concentrations of coarse and large PM adjacent to roadways to estimated concentrations of fine (PM2.5) particles and concentrations of nitrogen and phosphorus species in the same plumes. The fine fraction of road dust made up roughly 20% of the total mass and concentrations of nitrogen species and P were low. Although a substantial portion of the sampled road dust mass was not identified, the analyses nevertheless suggested that road dust did not contribute significantly to nitrogen concentrations in PM samples at LTADS ambient air quality stations.
Specifically, the laboratory analyses of the samples collected at Incline Village showed no nitrates above uncertainties, less than 0.2% ammonium ion barely above uncertainties, and no phosphorus above uncertainties. Incline Village can be considered a low density urban site. Sand Harbor can be considered typical of many road sections surrounding areas of the Lake with lower population density. The road dust samples from Sand Harbor had reported composition of less than 2.5% nitrates, less than 4% ammonium ion, and contained no detected phosphorus above uncertainties. The highest PM2.5 mass concentrations observed was in the dust samples from Incline Village. In this sample the PM2.5 mass comprised slightly more than half of the corresponding PM10 mass concentration. Chemical speciation of size resolved particles was based upon laboratory analysis of the TSP, PM10, and PM2.5 filter samples. Collection of filter samples limited to finer particles (e.g., submicron particles) within the PM2.5 fraction was not feasible logistically and funding for additional laboratory analyses was beyond the resources of the project.

Limited observations were also made of the effects on local ambient concentrations associated with application of traction control material to roads (Kuhns, et al., 2004). PM concentrations were measured before and after application sand or brine to a road in Sand Harbor area. Observed concentrations likely responded not only to changes in traffic volume and application of traction control materials but also to changes in wind speed and vertical mixing.

7.3.2 Motor Vehicle Emissions

To better understand the role of motor vehicle emissions and their impact on ambient concentrations, there were four areas of study. It was first necessary to characterize traffic volumes on various road types. Second the actual fleet composition was needed to compare with defaults in California's EMFAC. Because California registered vehicles

have a distinct emission profile as contrasted with the "50 state" vehicles, it was also necessary to identify the fraction of California registered vehicles in the Tahoe Basin. Finally, the connection between motor vehicle emissions and ambient concentrations required investigation. The UC Riverside College of Engineering Center for Environmental Research and Technology (CE-CERT) used survey techniques and observational data to address these areas of study (Fitz et al., 2004).

7.3.2.1 Motor Vehicle Activity Data

Motor vehicle activity data includes vehicle traffic volumes and fleet composition which are summarized in **Figures 7-8 through 7-11**. **Figure 7-8** illustrates the relative levels of activity on three types of roads in Tahoe Basin. This limited data suggests residential vehicle miles traveled (VMT) are limited to 15% of all VMT and that arterial and major arterial traffic exceeded residential traffic by a substantial margin. The fleet composition by vehicle type during winter and summer is contrasted in **Figure 7-9** with the assumptions from California's EMFAC motor vehicle emissions platform. From a quick review, it seems that EMFAC fleet population data fall between winter and summer profile at Tahoe and are thus fairly reasonable. However, it also appears that trucks observed at Tahoe are heavier. A comparison of fleet data collected at Tahoe City spring winter and summer with the default fleet composition in EMFAC indicates that EMFAC may over-estimate VMT for light duty vehicles and underestimated it for medium duty vehicles (**Figure 7-10**).

As expected, and confirmed in **Figure 7-11**, the fraction of California registered vehicles in Tahoe Basin decreases significantly on the Nevada side of the basin. The on-road mobile source emission inventory for the LTAB ideally should reflect Tahoe specific data such as was collected in these studies.

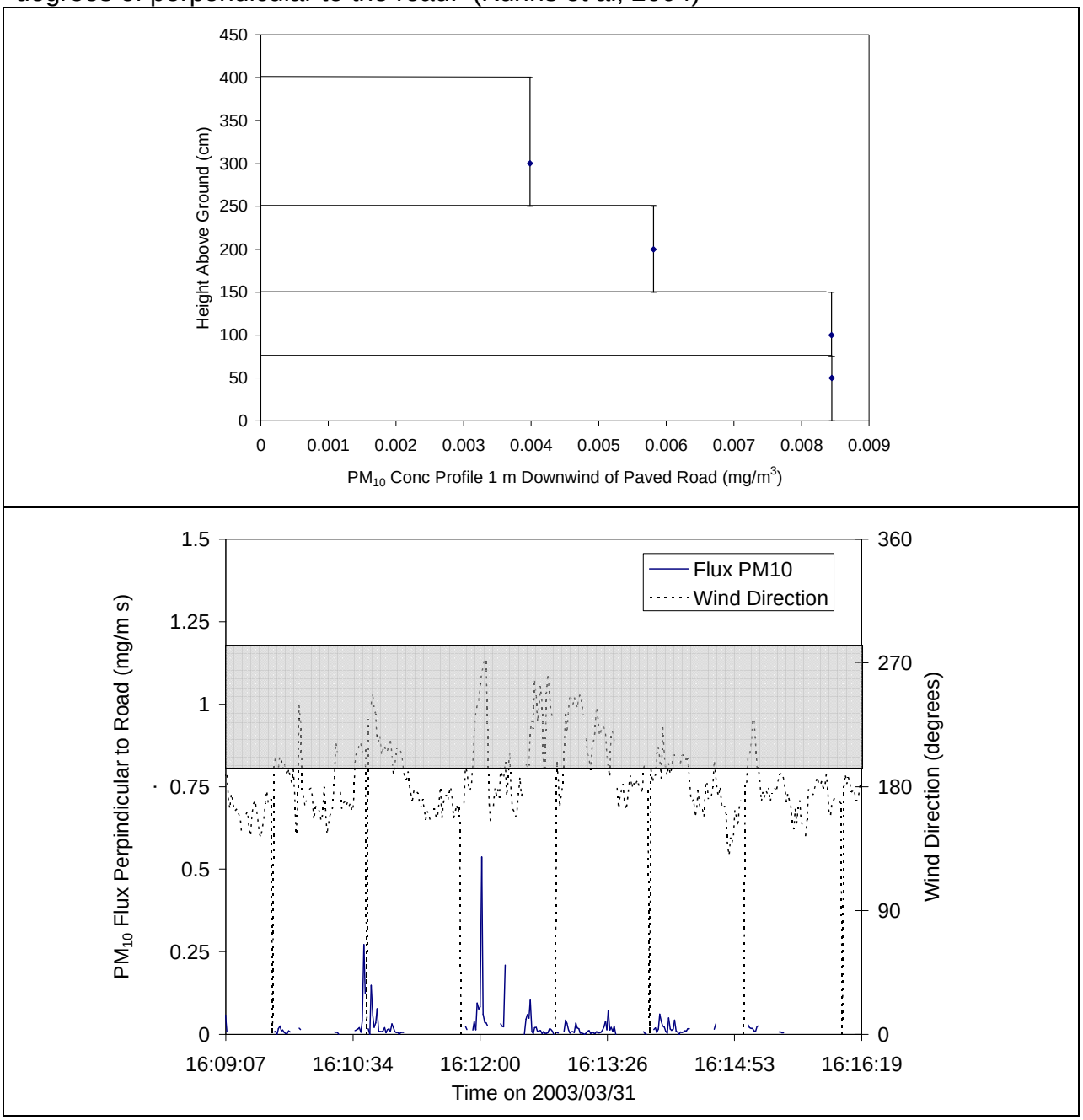
7.3.2.2 Observed Relationships Between Activity Levels and Near Source Concentrations

DustTraks (Kuhns, et al. 2004) and ELPI instruments (van Gulijk, et al. 2001 &2003) provided data to understand the connections between road activity patterns and ambient gas and particle concentrations. **Figure 7-12** provides evidence for the connection between road traffic and ambient concentrations. Ammonia, PM, CO_2, and CO concentration peaks were, in particular, related to traffic patterns.

The ambient samples obtained at road side obviously included motor vehicle emissions in addition to road dust. Accordingly, they contained a higher fraction of fine particles and organic materials than did the samples of resuspended road dust. On the other hand, phosphorus concentrations were so low as to be below the limits of detection.

Referring back to **Figure 7-5** and the DustTrak measurements in **Figure 7-12**, note that motor vehicle emissions are a substantial portion of the ammonia inventory in the Lake Tahoe Air Basin and that the observed ammonia concentrations are correlated with vehicle traffic. Reflecting on measurements taken at Incline Village, the DustTrak measurements match well with published data (Kuhns et al., 2004).

Figure 7-7. Vertical profile of PM concentration 1 m from paved road (upper panel) and time series of PM10 flux perpendicular to road from DustTraks and wind vane (lower panel). The shaded band represents the range of wind directions that are within 45 degrees of perpendicular to the road. (Kuhns et al, 2004)



Compared to ozone precursors there has been comparatively little study of ammonia emissions from mobile sources until recently. Ozone precursors, NOx and ROG, both must be well characterized when considering strategies to meet the federal ozone standard. Ammonia has been of interest from a regulatory perspective less frequently

and in far more limited geographic areas (primarily where ammonium nitrate aerosol was a significant fraction of PM2.5 concentrations during winter exceedances of the federal PM2.5 standard).

It appears that ammonia emitted from motor vehicles is an important contributor to ammonia concentrations and nitrogen deposition at Lake Tahoe. This conclusion is based on the observed spatial patterns in ambient concentrations and the emission inventory. LTADS ambient monitoring sites at the north and south shores were generally located near major roads and as noted previously, concentrations of gas phase nitrogen species were significantly higher at these sites compared to sites farther from traffic. In addition, the inventory identified motor vehicles as one of the largest sources of ammonia emissions in the basin. The emission inventory information and the location of roads near the Lake indicate the importance of motor vehicle emissions.

Figure 7-8. Motor vehicle traffic volumes on three types of Tahoe Basin roads. (Fitz et al, 2004)

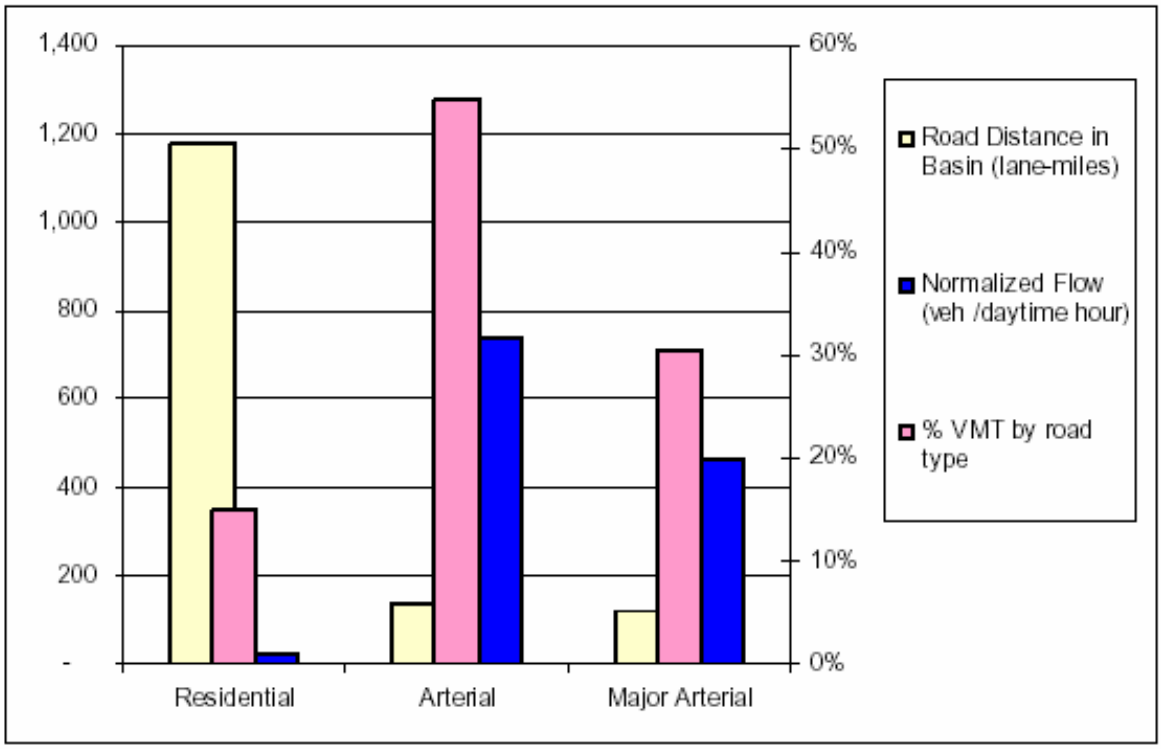


Figure 7-9. Fleet distribution at Tahoe City in comparison with current emissions model. (Fitz et al, 2004)

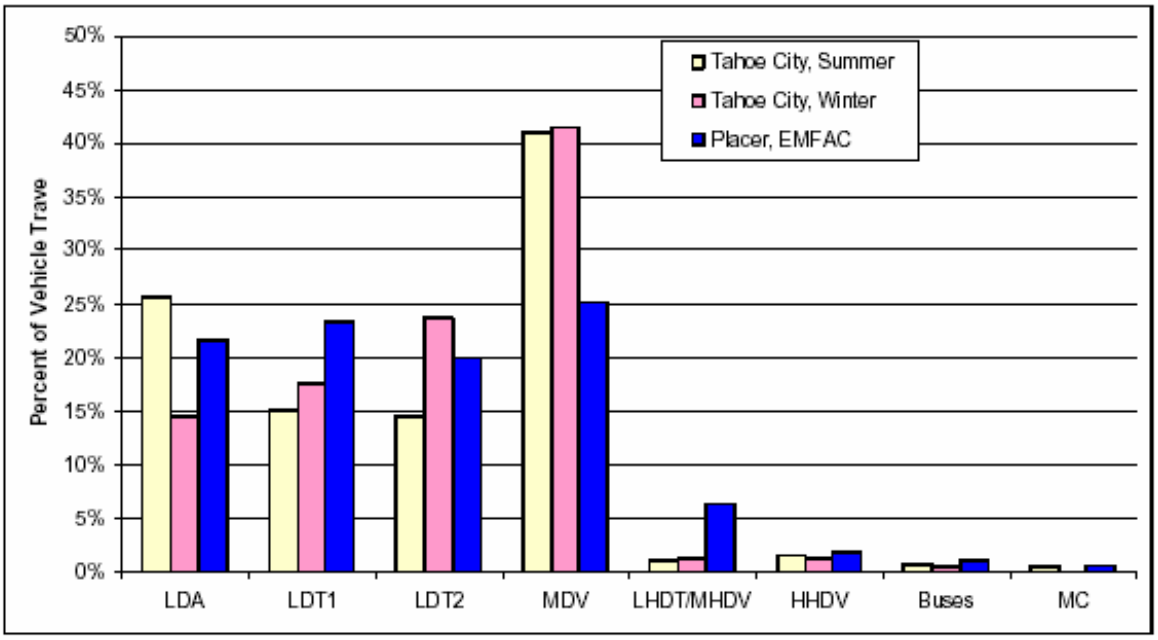


Figure 7-10. Fleet distribution in Tahoe Valley in comparison with current emissions model. (Fitz et al, 2004)

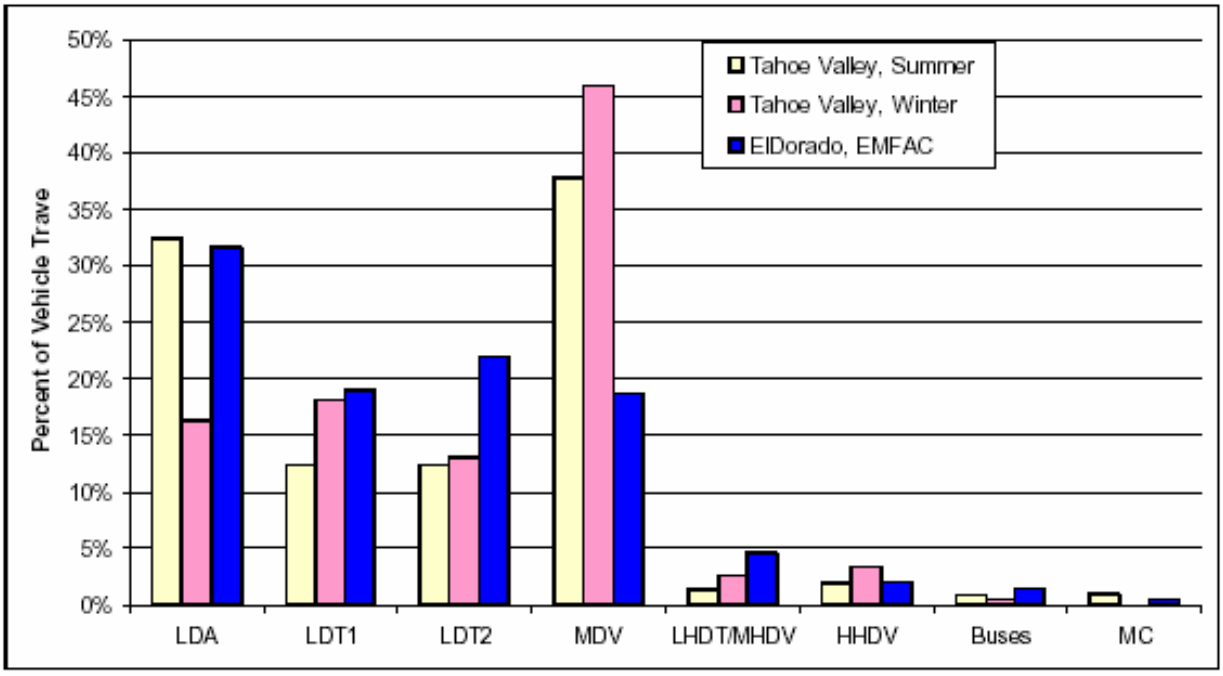


Figure 7-11. Fraction of California-registered vehicles in Tahoe Basin. (Fitz et al, 2004)

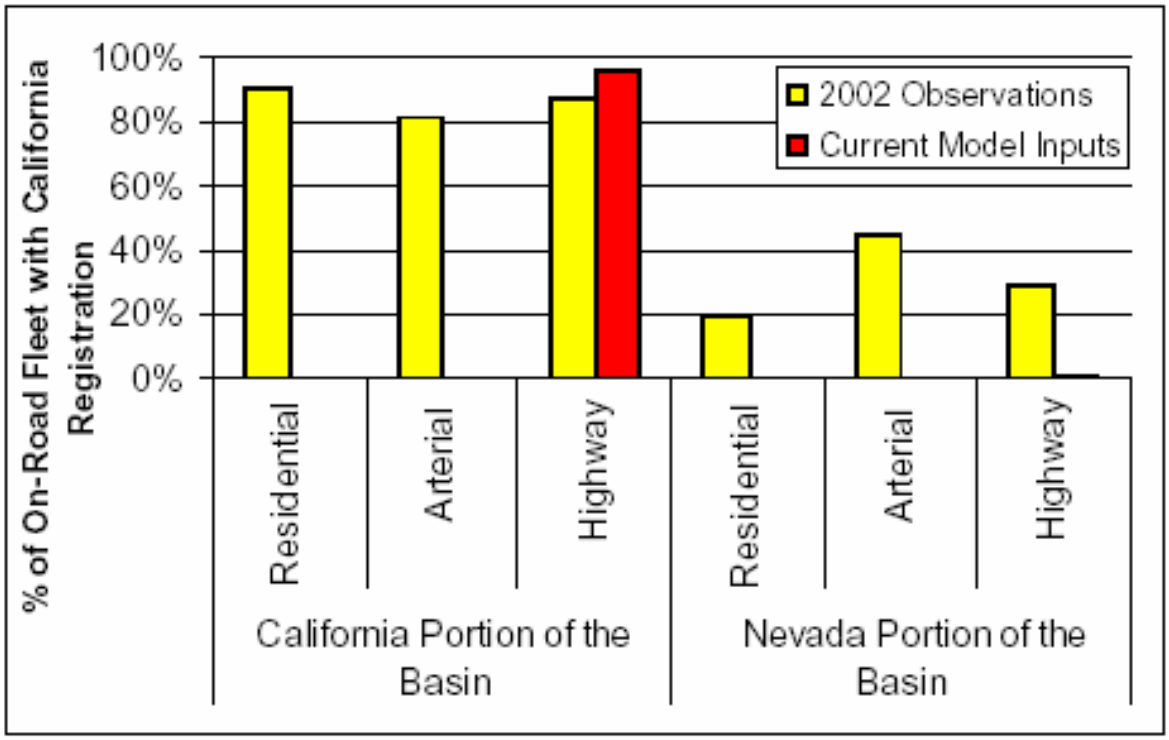
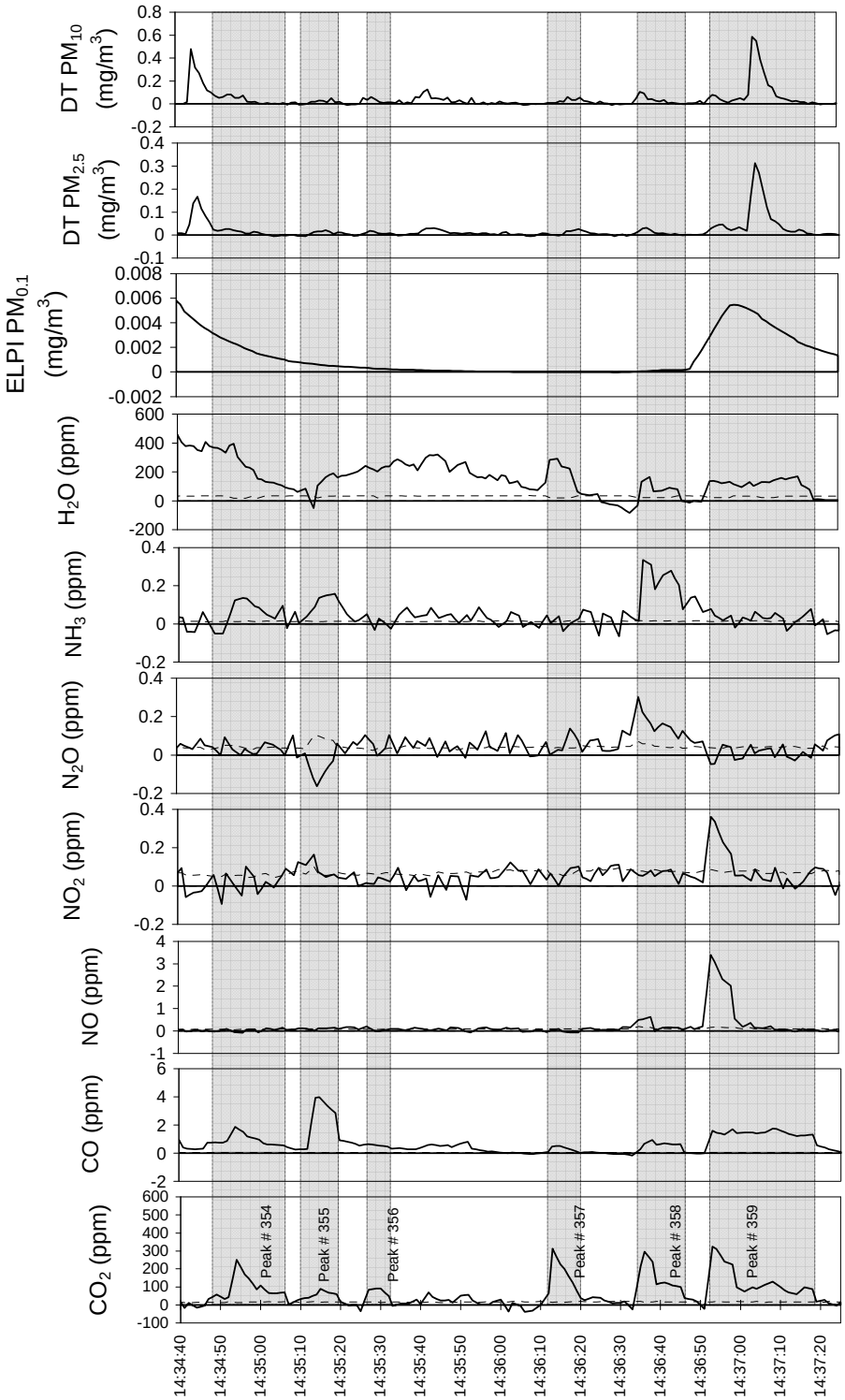


Figure 7-12. Time series of CO_2, CO, NO, NO_2, N_2O, NH_3, H_2O, and PM measured by ELPI and DustTracks. Shading indicates periods when measured concentrations are linked to passage of vehicles. Dashed black line represents the analytical uncertainty of gas phase measurements. (Kuhns et al, 2004)

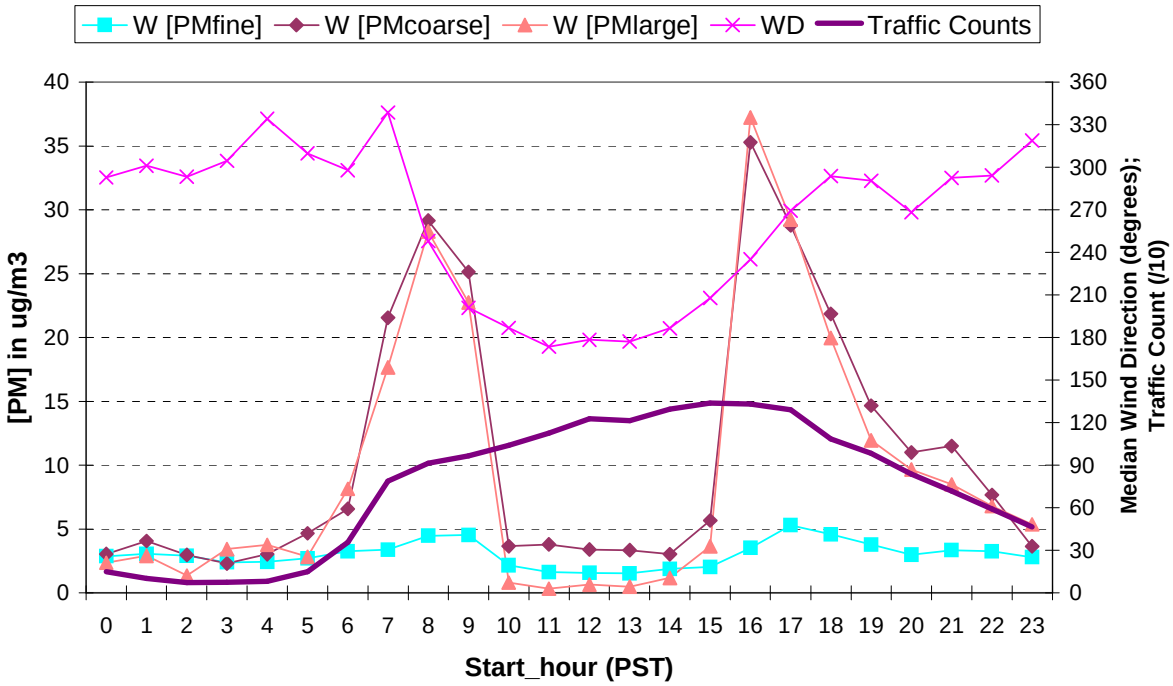


7.3.2.3 Connections between Motor Vehicle Activity & Ambient Concentrations

Beta Attenuation Monitors (BAM) were deployed during LTADS to provide hourly PM concentrations. Summaries of the hourly PM data and integration with meteorological data (e.g., wind directions) were used to provide a better understanding of the PM sources. The influence of motor vehicle emissions on PM concentrations at the Lake Forest Station is evident in **Figure 7-13**. PM concentrations observed at Lake Forest Station peak when traffic counts are high and the station is downwind of the roadway. A rapid decrease in concentrations occurred when the wind direction shifted to onshore in midmorning. Similarly a rapid increase in concentrations occurred in late afternoon when the wind direction began switching to downslope and offshore and the monitoring site was once again downwind of the roadway emissions. Winds blowing with a northerly component brought fresh motor vehicle and road dust emissions to the monitoring location while winds blowing from the south were onshore winds that blew roadway emissions away from the site. Traffic volumes increased rapidly after 5 a.m., remained high throughout the day, and tapered off during the evening. Even fine PM concentrations indicate some peaking during traditional traffic commute hours only to fall in mid-morning when the wind direction became onshore.

Similar observations of PM were made with BAMs at the Sandy Way and SOLA sites in South Lake Tahoe. At those sites located on either side of Highway 50, the PM concentrations were also observed to respond to emissions of road dust according to the diurnal shifts in wind direction (in the morning from downslope flow to upslope flow and in the late afternoon from onshore upslope flow to offshore downslope flow).

Figure 7-13. Lake Forest Mean PM by size, Wind Direction, & Traffic Counts in Winter.



As illustrated in **Figure 7-14**, PM concentrations tended to peak around typical commute periods and thus are indicative of the large role road dust plays in determining ambient air quality. The effect is particularly enhanced during winter when road sanding material is applied and swept up. In reality, the sanding material effect is stronger than shown because the winter has periods of precipitation and storms that reduce the seasonal average of ambient concentrations. Thus, during post-storm periods when winds are light, PM concentrations can be very high. Conditions on a sample day (January 3, 2003) are presented in **Figure 7-15**. Winds were light (3-4 knots during the early morning hours, 1-2 knots during most of the day, and calm at 23:00) but exhibited typical diurnal variations in direction (i.e., upslope/onshore during the daylight hours and downslope/offshore during darkness); winds from the north, east, south, and west respectively correspond to 360^{O}, 90^{O}, 180^{O}, and 270^{O}. Note the large increase in TSP concentration at the SOLA site during the morning commute. The SOLA site is located north of Highway 50 and less than 50 yards from the roadway. The increase in TSP concentrations is not as large at the Sandy Way site because it is located a block south of Highway 50 and its measurements are from the top of a 1-story building. When the airflow reverses to onshore/upslope later in the morning, concentrations decline at the SOLA site but now increase at the Sandy Way site which is now downwind of Highway 50. Note that most of the TSP at Sandy Way at this time is from aerosols in the PM_coarse (2.5 µm < PM_diameter < 10 µm) and PM_large (10 µm < PM_diameter) sizes, which is consistent with road dust as the principle source of the material. Later in the afternoon when the airflow reverses direction again, TSP concentrations at SOLA increase while TSP at Sandy Way declines but does not become clean. Note in the evening that the PM2.5 concentrations increase dramatically and provide the bulk of the TSP concentration at that site. As indicated by the emissions figure (**Figure 7-1**) and the timing of the emissions, the PM2.5 is likely wood smoke from residential fuel combustion.

On numerous occasions during LTADS, TSP concentrations at the SOLA site would change by more than 99 $\mu g/m^3$. A summary of these instances, after screening for potentially spurious single hour events, is presented in **Figure 7-16** by season and hour of the day. Note that the majority of events occur during the winter and spring when road-sanding material is likely present. Also note that the times of the occurrences are consistent with a combination of increased motor vehicle activity (**Figure 7-17**) and stable atmospheric periods (e.g., low wind speeds during the transitions between downslope and upslope air flow, strong ground-level temperature inversions during the night). The occurrence of early morning PM spikes is rather unique to the SOLA monitoring site and not fully understood. However, a potential cause may be early morning traffic associated with the casinos in nearby Stateline. The traffic-counting site at Rufus Avenue is near the SOLA air quality site. When normalized to mid-week traffic volumes, the late night and early morning traffic volumes are 2-3 times higher on weekends and holidays (**Figure 7-18**). Thus, traffic associated with early morning gaming and entertainment activities on weekends may account for the bulk of the early morning spikes in PM concentrations.

The morning and evening commute periods also happen to occur near the times of transition between up-slope and down-slope airflows. Mean TSP concentrations associated with 1-hour reversals of wind direction (i.e., from offshore to onshore, typically in mid-morning, and from onshore to offshore, typically in evening) are plotted in **Figure 7-19** for the Cave Rock site, which is primarily impacted by motor vehicles. The site is located on the east side of Lake Tahoe (Nevada) and situated between Highway 50 and the Lake. Note that, except for winter mornings, the TSP concentrations are appreciably higher during offshore flow than during onshore flow. The change in TSP concentrations with change in wind direction is greatest during the morning in spring and summer and is greatest during the evening in fall and winter. This pattern is primarily due to days being shorter during fall and winter than during spring and summer and temporally matching the evening traffic period better.

The two TSP BAM monitoring sites in South Lake Tahoe, SOLA and Sandy Way, were located near each other with the SOLA site being north of Highway 50 and the Sandy Way site being 1 block south of Highway 50. Thus, the sites alternately detect the effects of traffic on Highway 50 during downslope and upslope airflow. The difference in TSP concentrations between the two sites (SOLA minus Sandy Way) is plotted by hour and season in **Figures 7-20 through 7-23**. When the difference is positive, TSP concentrations were higher at SOLA than at Sandy Way; when the difference is negative, TSP concentrations were lower at SOLA than at Sandy Way. Although there is some “noise” around the zero line due to “sloshing” of the air mass during shifts in wind direction, the plots obviously indicate influence of Highway 50 on TSP concentrations – TSP concentrations are higher at SOLA when the wind is offshore and higher at Sandy Way when winds are onshore.

Denuder measurements of ammonia and nitric acid at the nearby TWS sites in South Lake Tahoe (SOLA and Sandy Way) are plotted by TWS sampling period in **Figure 7-24**. **Figure 7-24** indicates better atmospheric mixing in the spring and early summer as concentrations are lower and more similar between the two sites. Because HNO_3 is a secondary (formed from chemical reactions in the atmosphere) pollutant, its concentrations tend to be more similar at the two nearby sites and exhibits less seasonal variation than the NH_3, which is a primary (directly emitted) pollutant, does. The differences in concentrations at the two sites (SW minus SOLA) are shown for each 2-week period in **Figure 7-25**. Negative values indicate that concentrations are higher at the SOLA site than the Sandy Way site. Although the nitric acid difference shows some variation, the ammonia concentrations are consistently higher at SOLA than at SW, although the difference is smaller during spring. The higher NH_3 at SOLA than at SW could be due to a couple of factors: its closer proximity to motor vehicle and biogenic emissions (SOLA site on open ground and near Highway 50 while SW site is on a roof in a paved area with little ground exposure). Because the [NH_3]s are highest in winter and the snow cover would absorb the NH_3 emissions from the ground and because [NH_3]s at SOLA are 2 times those at SW and 8 times those at Thunderbird, which has good biogenic exposure but not motor vehicle exposure, motor vehicles would seem to be a primary source of ammonia emissions at the SOLA site.

Figure 7-14. Seasonal mean diurnal TSP concentrations at SOLA in ug/m^3.

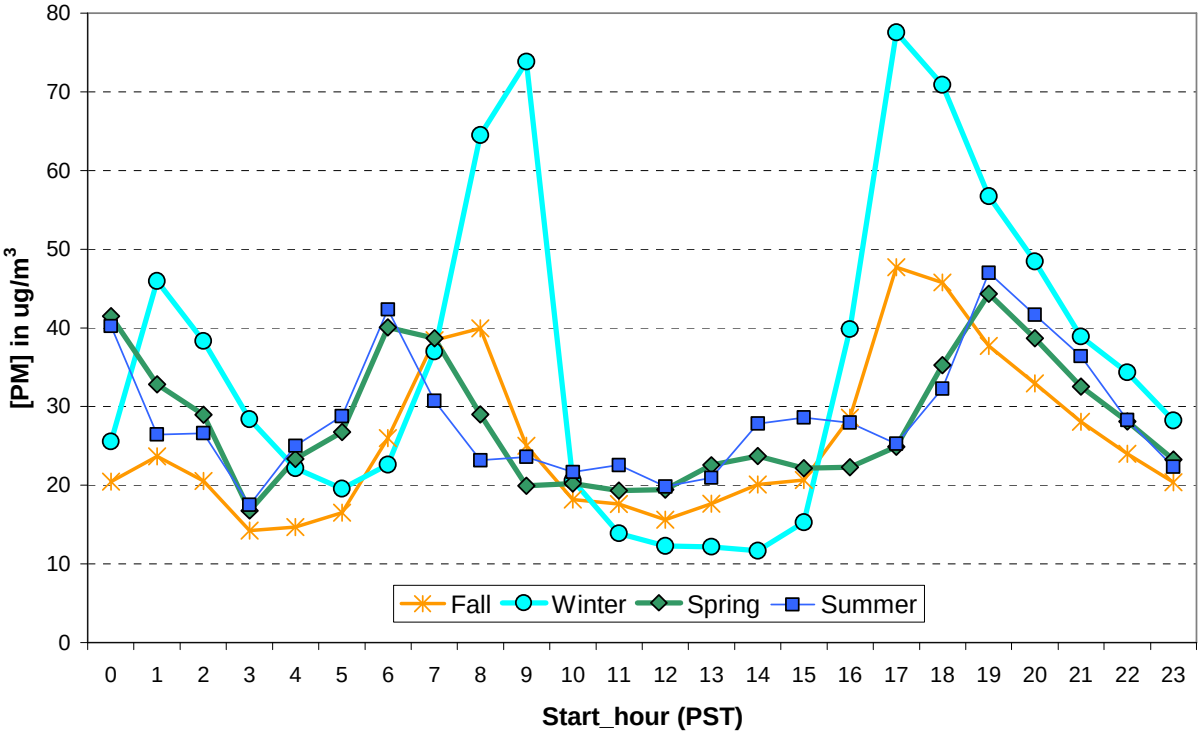


Figure 7-15. Observations reported for January 3, 2003.

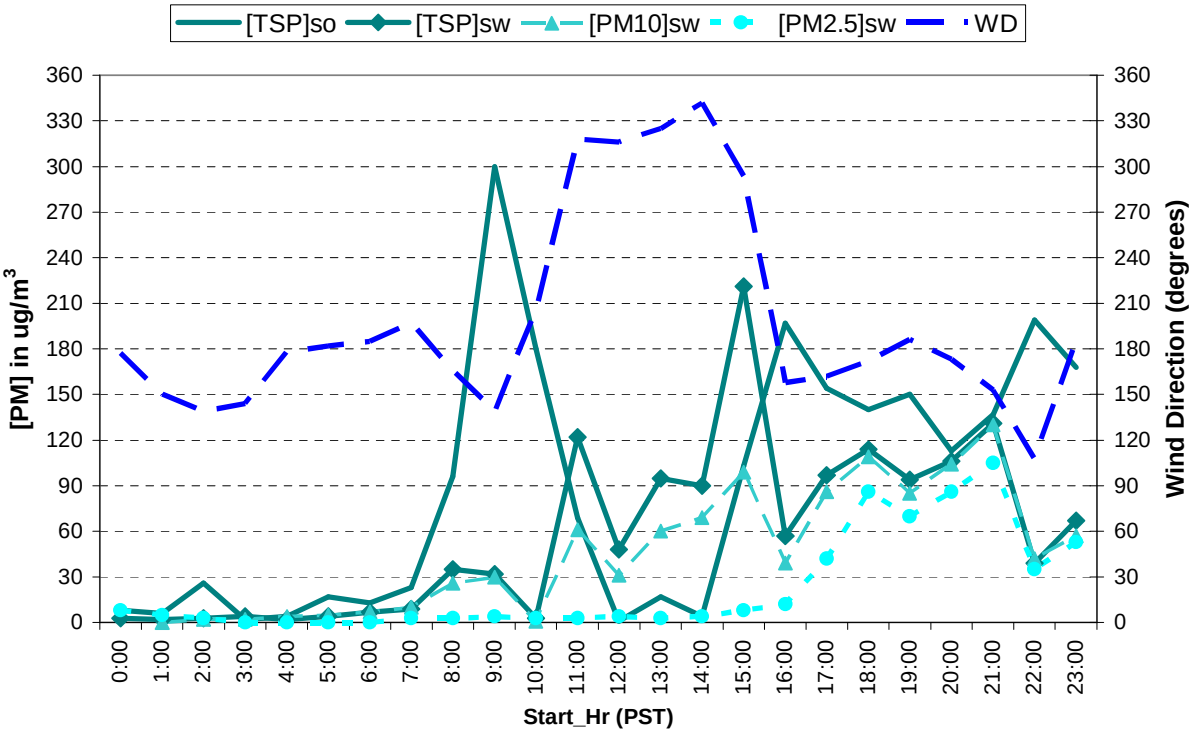


Figure 7-16. Count of instances when edited [TSP] at SOLA changed more than 99 ug/m^3 in one hour.

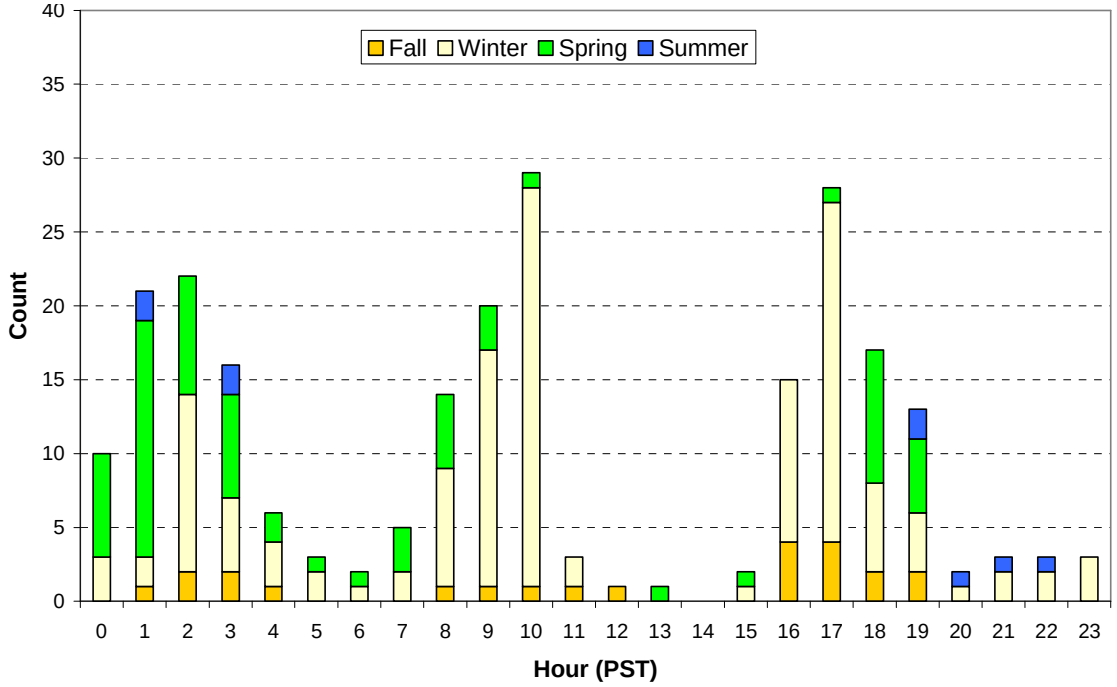


Figure 7-17. Traffic volumes based on measurements on Highway 50 near Rufus Avenue.

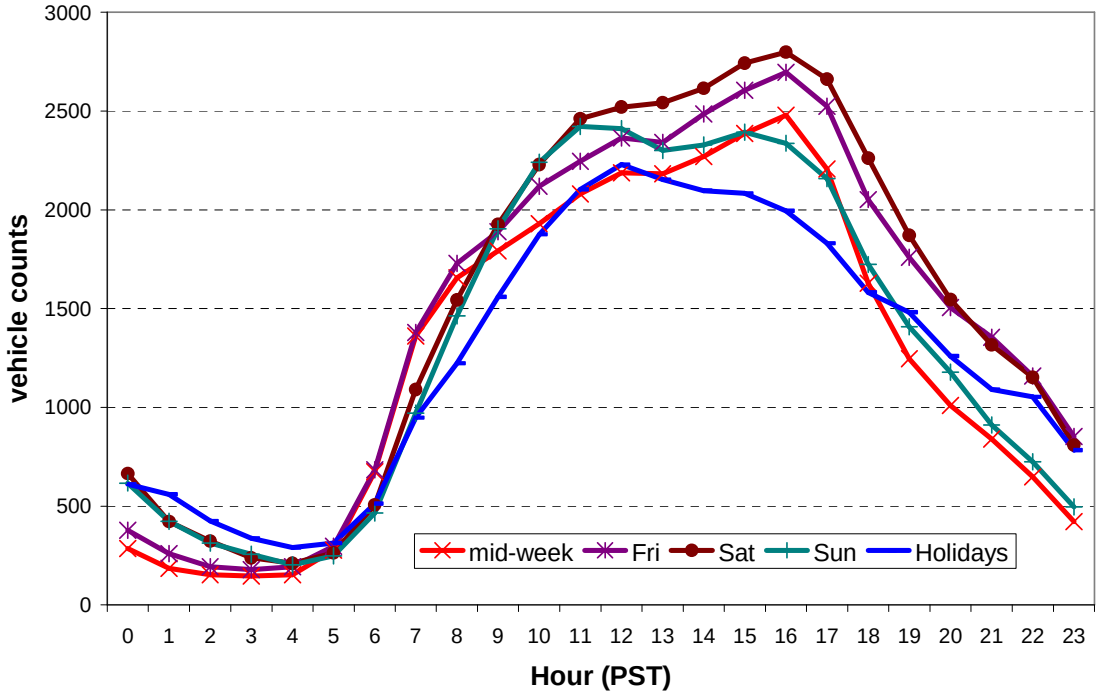


Figure 7-18. Traffic volumes on Highway 50 near Rufus Avenue normalized to mid-week traffic volumes.

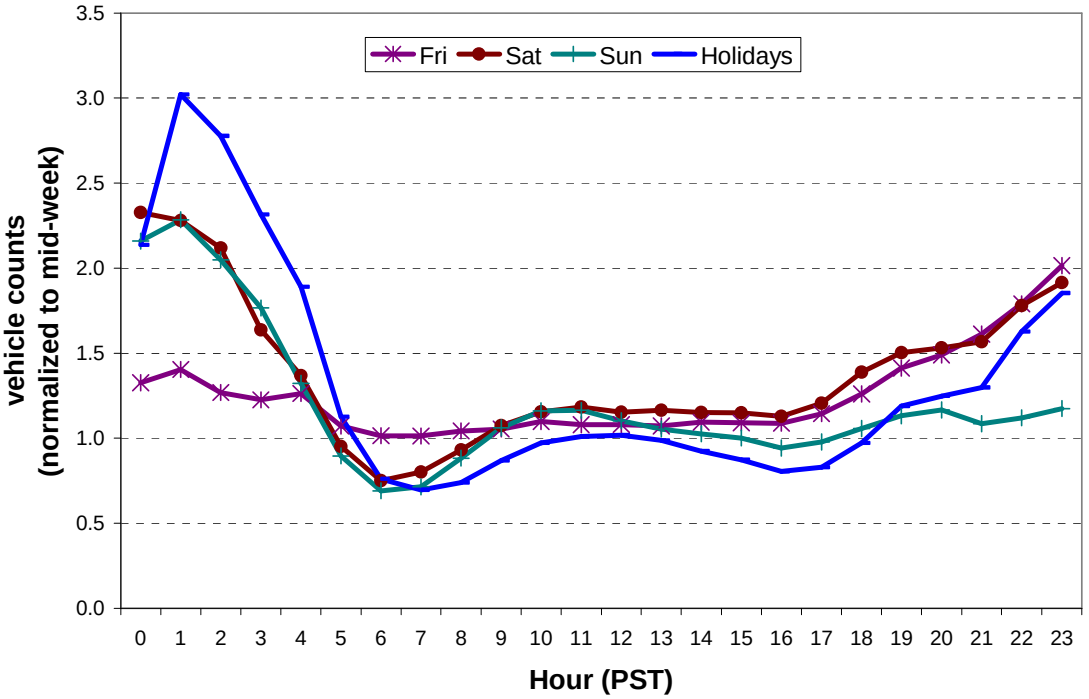


Figure 7-19. Mean TSP concentrations at Cave Rock associated with 1-hour reversals in wind direction during 2003. (Note: The orange plots represent the TSP during the wind reversal from offshore to onshore in the morning while the turquoise plots represent the TSP during the wind reversal from onshore to offshore in the evening. The darker shading represents the concentrations during offshore airflow while the lighter shading represents concentrations during onshore airflow.)

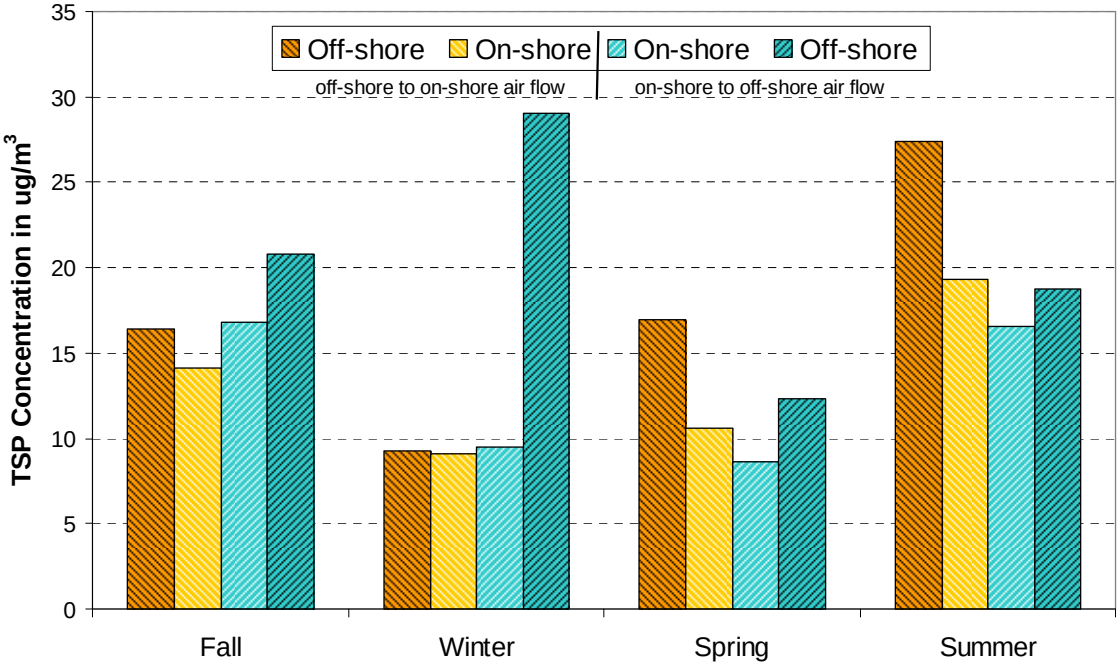


Figure 7-20. Difference in TSP concentrations at SOLA and Sandy Way (SOLA – SW) associated with offshore and onshore wind directions during winter months of 2003.

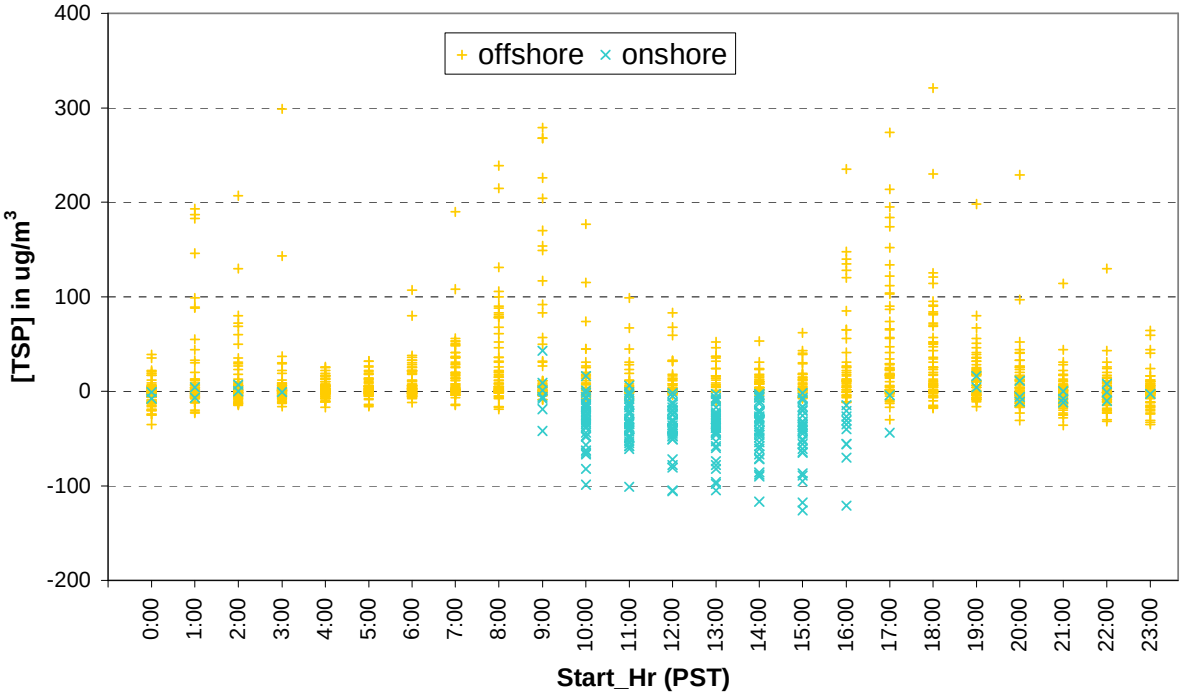


Figure 7-21. Difference in TSP concentrations at SOLA and Sandy Way (SOLA – SW) associated with offshore and onshore wind directions during spring months of 2003.

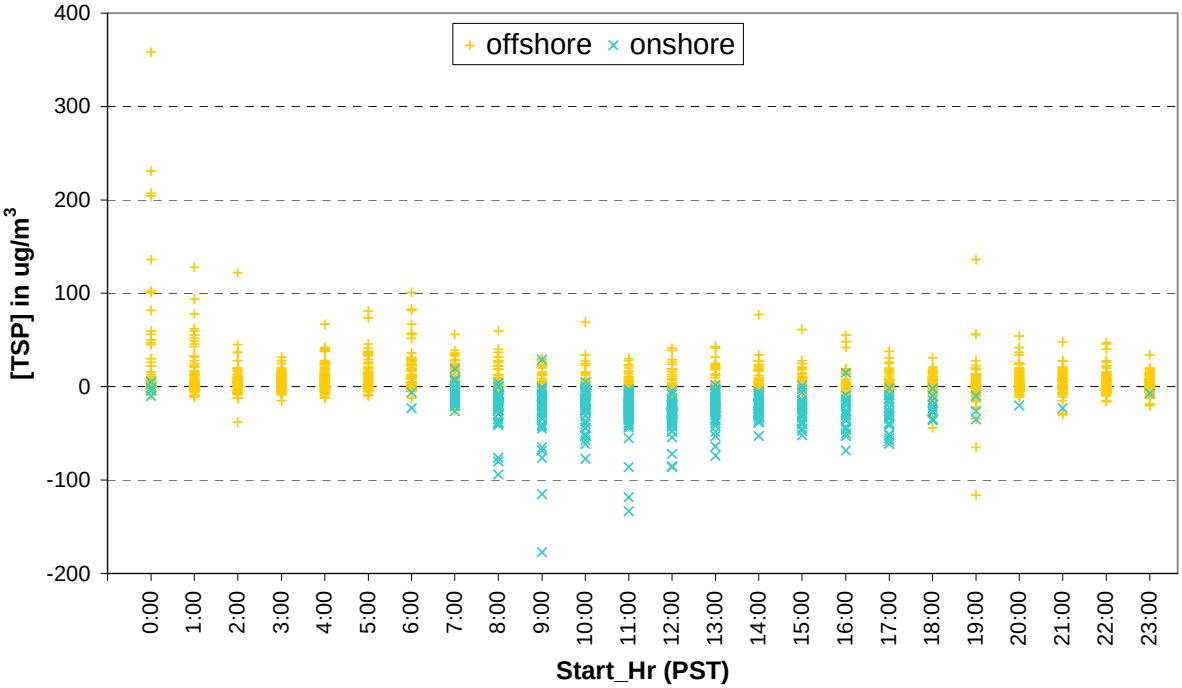


Figure 7-22. Difference in TSP concentrations at SOLA and Sandy Way (SOLA – SW) associated with offshore and onshore wind directions during summer months of 2003.

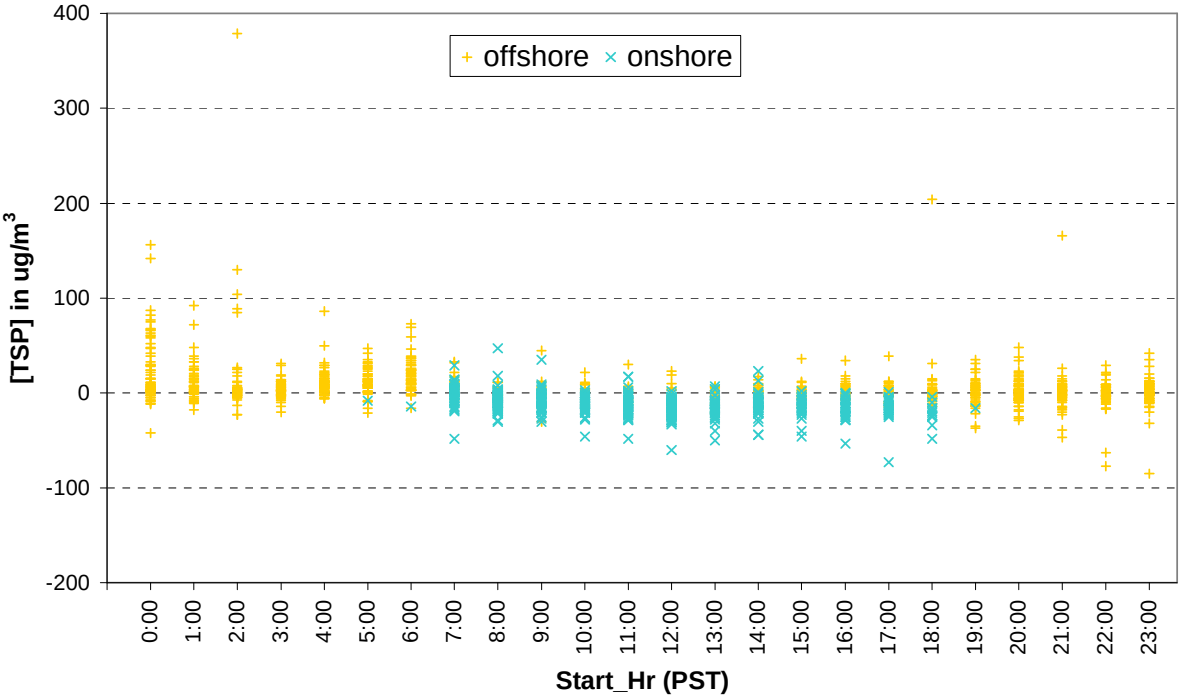


Figure 7-23. Difference in TSP concentrations at SOLA and Sandy Way (SOLA – SW) associated with offshore and onshore wind directions during fall months of 2003.

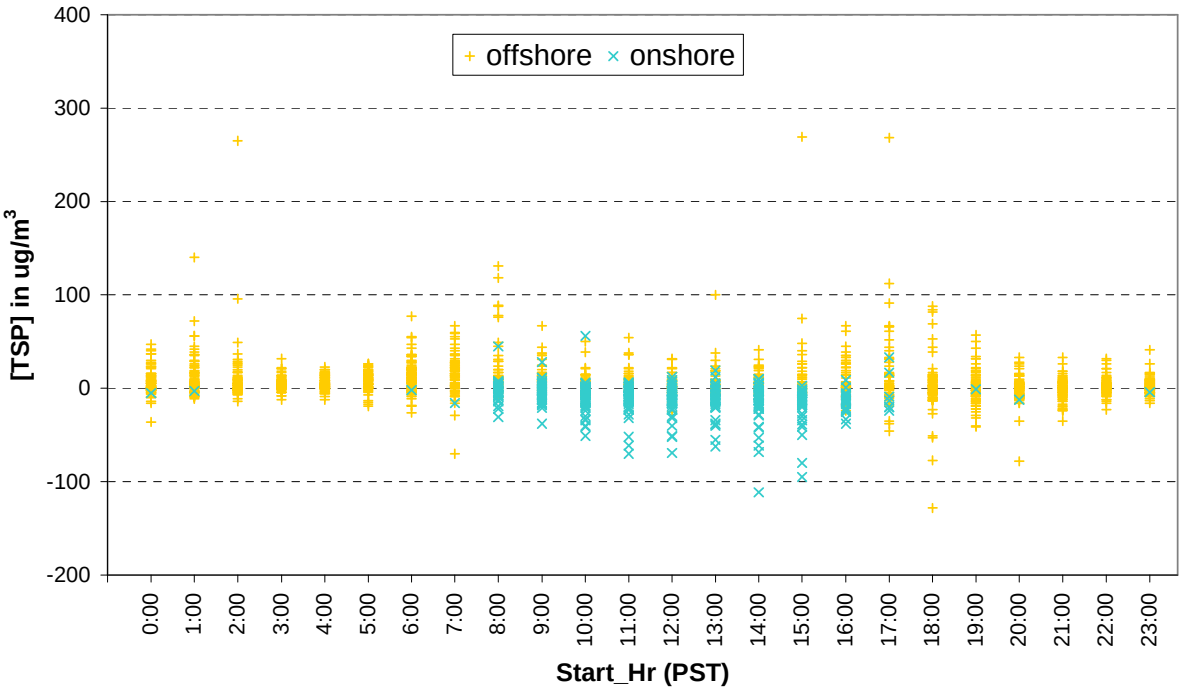


Figure 7-24. Temporal variation in ammonia and nitric acid concentrations at South Lake Tahoe sites (Sandy Way and SOLA) based on TWS program.

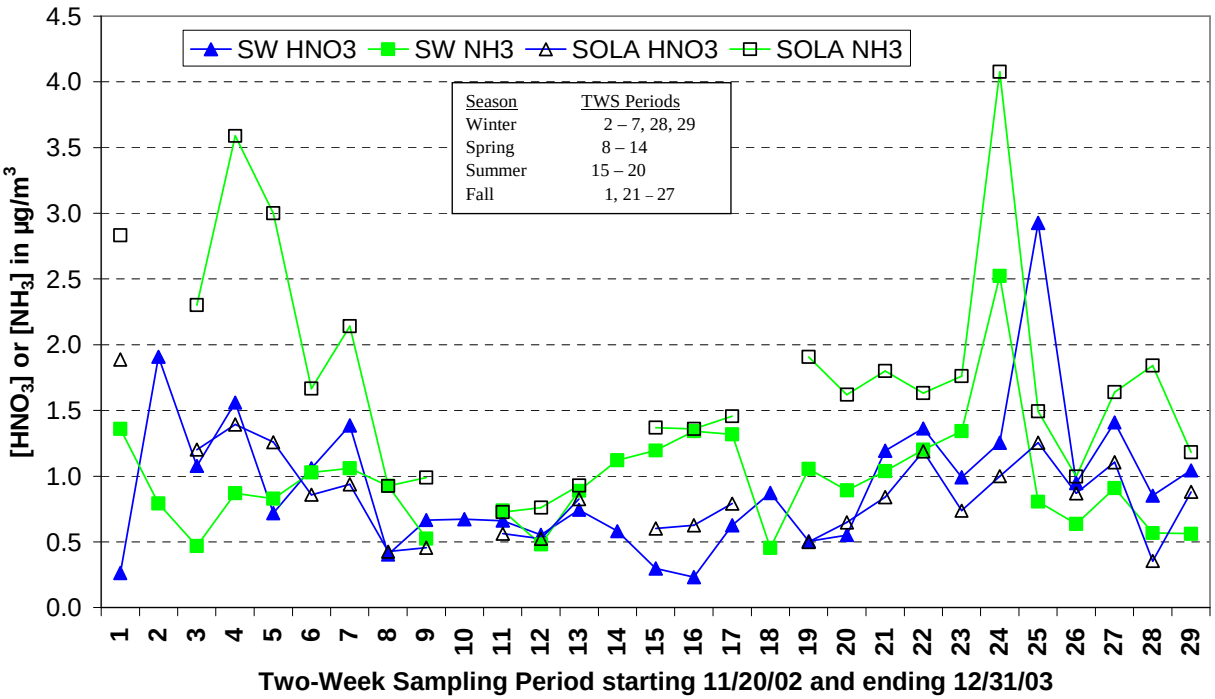
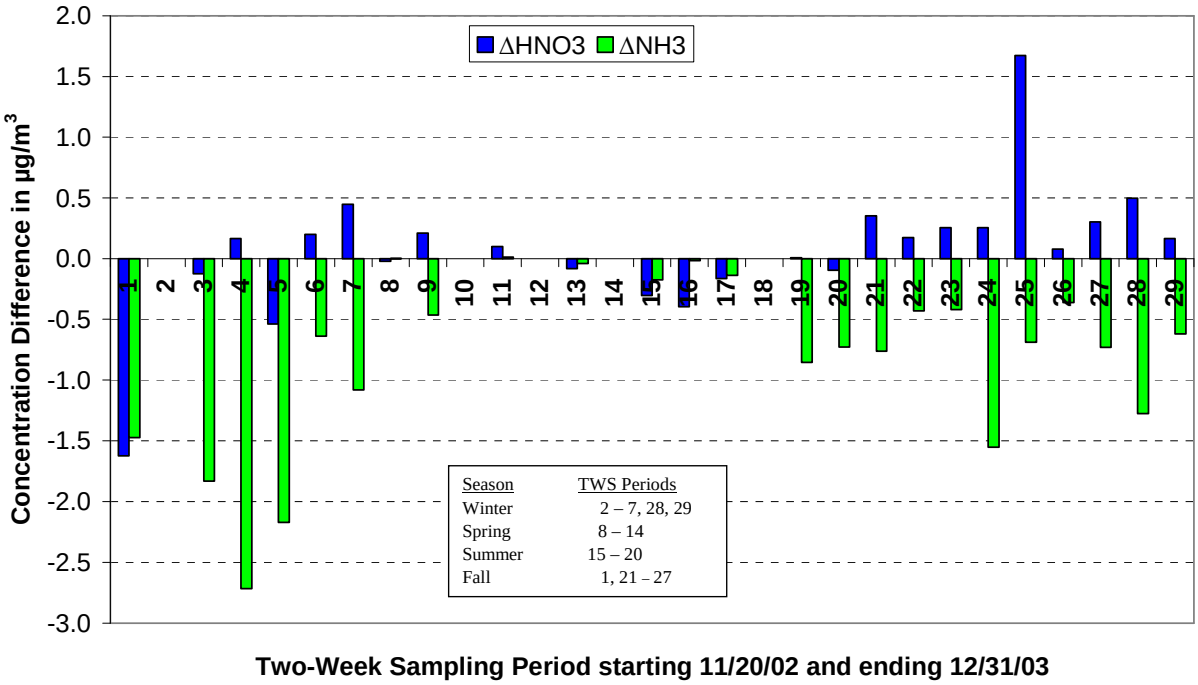


Figure 7-25. Sandy Way minus SOLA differences in ammonia and nitric acid concentrations in South Lake Tahoe.



7.3.3 Residential Wood Smoke Emissions

LTADS approached residential wood smoke source characterization through residential chimney sampling (Kuhns et al., 2004) and neighborhood sampling (Fitz et al., 2004). We expected that fire place and wood stove plumes would enter the larger neighborhood volume of air and chimney emission concentrations would quickly disperse and deposit leading to lower concentrations for neighborhood samples. These lower concentrations would then better represent ambient air concentrations.

Using EPA Method 28 source testing, DRI analyses showed that substantial mass of particulate matter, nitrates, ammonium, and organic matter were emitted in the chimney smoke. Source profiles are generally used to provide pollutant emission factors, the ratios of the emitted constituents to the total mass of particulate matter sampled (Kuhns et al., 2004). Phosphorus was not observed in the chimney smoke at concentrations greater than the measurement uncertainty. This result is not unexpected as previous measurements characterizing P in firewood also report very little P. In fact, based on these earlier studies, the official P emission factor for firewood in ARB's emission inventory is zero. Official P emission factors are higher however for other types of fires because they contain live or recently alive vegetation which contains much more phosphorus. Official P emission factors are much higher than smoke for other common PM sources in the Tahoe Basin as indicated by **Table 7-1** and **Figure 7-26**. The ARB emission inventory also indicates that only about 5% of the total P atoms in road dust is found in soluble form, i.e., phosphates ($PO_4^{=}$).

As a result of limited surveys conducted during LTADS, a few generalizations can be made. The proportion of wood burning appliances was 59% wood stove, 25% fireplace without insert, 10% fireplace with insert, and 6% pellet stove. The average camper burned four logs per evening during the summer months and the average resident burned 7.4 logs over six hours during winter months.

As noted before, the neighborhood wood smoke profiles, collected by CE-CERT in the ambient air, are highly diluted compared to the concentrations measured in the source testing (Fitz et al., 2004). They reported filter sample mass and the results of elemental analysis with XRF. As the stack plume is dispersed and as heavier particles likely deposit out of the plume, concentrations are substantially reduced. As these source concentrations disperse and deposit to reach ambient air concentrations, PM10 mass is reduced by over 400 times and PM2.5 mass is reduced by over 800 times.

Figures 7-27a and 7-27b show the relative abundance of chemical species in the emissions from combustion of a hardwood (almond) and a soft wood (pine). After carbon and potassium, gas phase ammonia appears to be next highest species emitted from residential wood smoke.

Major chemical components of wood burning particulate matter emissions were organic carbon (OC) and elemental carbon (EC). Total Carbon (TC) accounted for 15% to 74%

of PM2.5 mass and TC fraction of PM2.5 mass from hardwood were generally higher than from softwood and higher from fireplaces than from wood stoves. Crustal elements were found with high variability, probably contributed from ambient background during sample collection.

Table 7-1. Phosphorus PM source profiles in CARB emission inventory. (CARB, 2002)

WEIGHT % of TSP	***WEIGHT % of PM 10***	***WEIGHT % of PM 2.5***	***PM PROFILE NAME***
0.7532	1.0695	0.8142	livestock operations dust
0.2723	0.2723	0.2723	PAVED ROAD DUST*
0.1602	0.1944	0.1997	windblown dust-unpaved rd/area
0.1499	0.1979	0.2273	CONSTRUCTION DUST
0.1499	0.1979	0.2273	landfill dust
0.1250	0.1250	0.1250	tire wear
0.1249	0.1679	0.1975	agricultural tilling dust
0.1249	0.1679	0.1975	windblown dust-agricultural lands
0.1096	0.1096	0.1096	UNPAVED ROAD DUST
0.0301	0.0301	0.0215	agricultural burning - field crops
0.0301	0.0301	0.0215	weed abatement burning
0.0295	0.0295	0.0205	grass/woodland fires
0.0295	0.0295	0.0205	open burning
0.0295	0.0295	0.0205	range improvement burning
0.0295	0.0295	0.0205	WASTE BURNING
0.0288	0.0288	0.0196	orchard prunings burning
0.0199	0.0199	0.0098	forest management burning
0.0199	0.0199	0.0098	timber and brush fires
0.0123	0.0127	0.0056	diesel vehicle exhaust
0.0000	0.0000	0.0000	brake wear
0.0000	0.0000	0.0000	FIREPLACES AND WOODSTOVES

* Official paved road dust factor. However, removal of an outlier data point, results in a P emission factor of 0.1372 for Paved Road Dust.

Note #1: These factors (dated 9/27/02) do not include newly discovered, potentially large self absorption correction factors for PM > 2.5 µm.

Note #2: Data from Turn et al. (1997), indicate comparable P fractions with pine slash burn (n=4 and 2 samples (Doug fir for PM2.5 & PM10) > uncertainty) P2.5 ~0.0097 and P10 ~0.0200 and fruit tree prunings (n=4 & none > uncertainty) P2.5 ~0.0200 and P10 ~0.0290).

Note #3: The PM sources shown in capital letters are the major PM sources in the Lake Tahoe Air Basin.

Figure 7-26. Ranking of phosphorus abundance in particulate matter sources (P as % of PM by weight) based on source profiles in CARB emission inventory. PM emission categories shown in capital letters are the main PM sources in the Tahoe Basin.

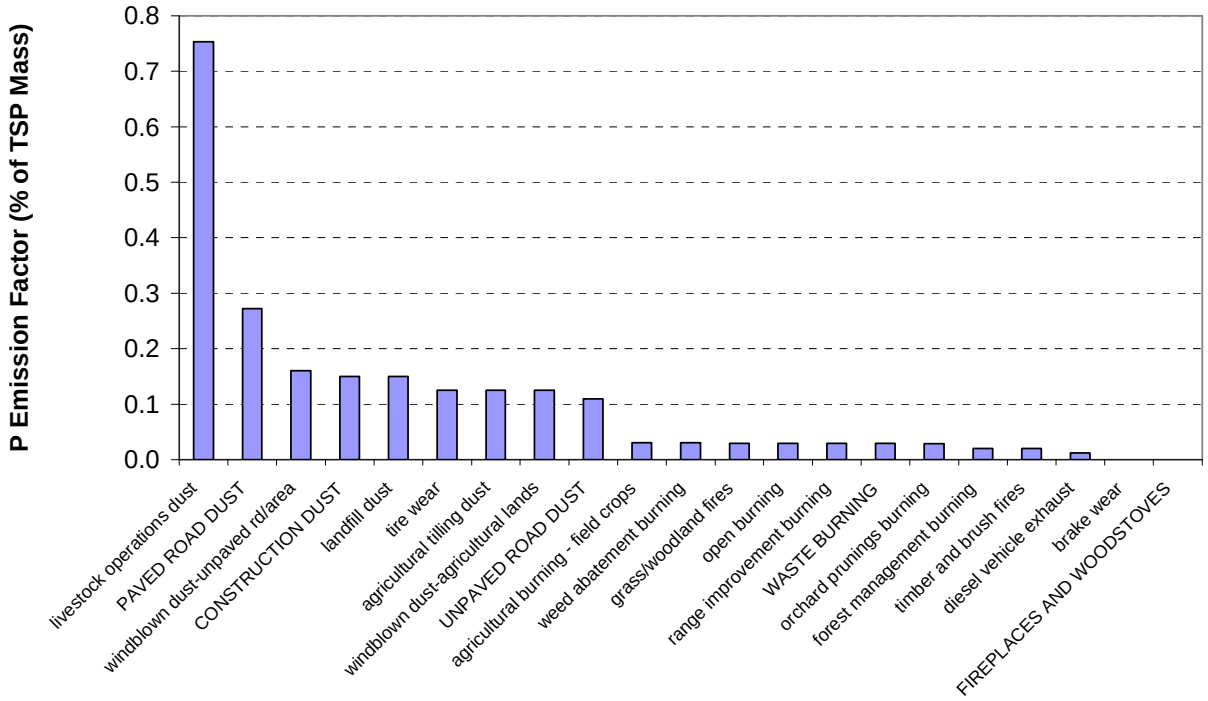
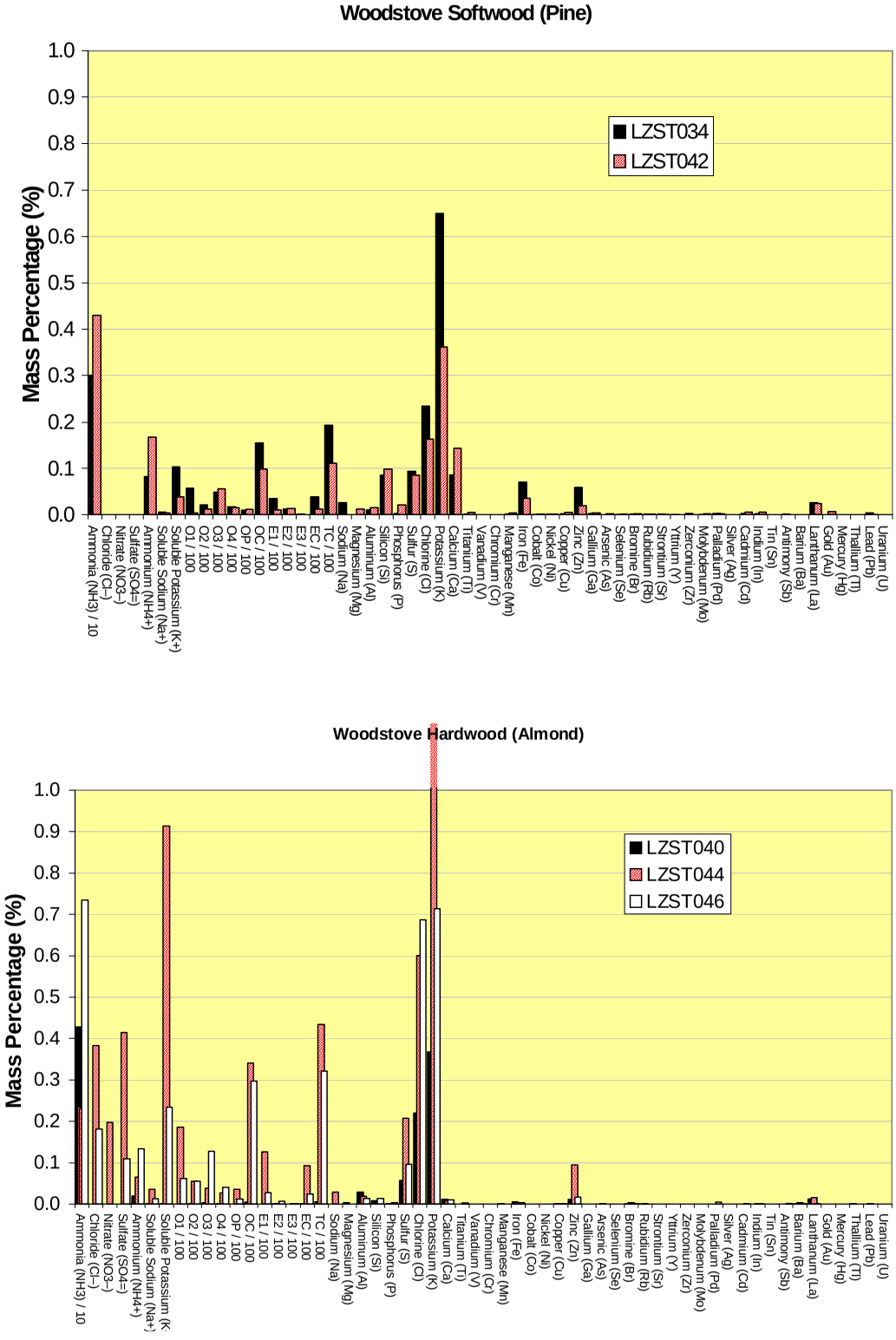


Figure 7-27. Comparison of the relative abundance of chemical species in wood stove emissions from combustion of a soft wood (pine) and a hard wood (almond) based on DRI analyses. (Kuhns et al, 2004)



7.4 Natural Nutrient and Particulate Sources

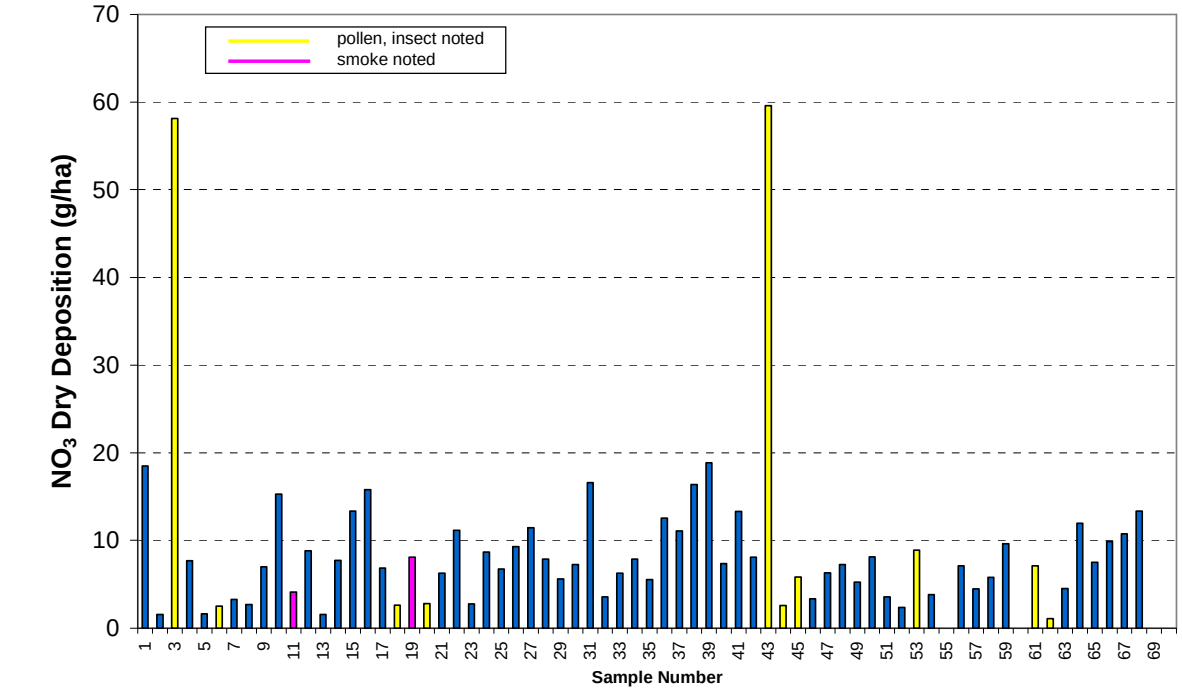
As alluded to earlier in the emission source profiles, natural processes contribute to the emissions of ammonia, phosphorus, and particulate matter. If particular significance, related to comparison of LTADS results with TRG surrogate surface results, which can collect larger particles than the LTADS samplers, is the apparent influence of natural sources, particularly pollen. The extensive forest of pine trees in the Basin generate a large quantity of pollen, particularly in the late spring and early summer when anecdotal reports indicate extensive pollen covering surfaces, including the lake's surface. The results of the laboratory analyses conducted on the surrogate surface dry deposition samples collected by the TRG indicate that pollen and smoke can significantly increase the amount of nutrients to Lake Tahoe. Analytical results of dry deposition samples collected at TRG's Ward Lake Level (aka Wallis Tower) sampling site are plotted in **Figures 7-28 and 7-29** for the samples collected between May 1, 2002 and March 31, 2004. The estimated dry deposition rates (grams per hectare; g/ha) of nitrates and total Kjeldahl nitrogen (primarily ammonia) associated with each sample are plotted in **Figure 7-28**. Similarly, the estimated dry deposition rates of dissolved phosphorus and total phosphorus associated with each sample are plotted in **Figure 7-29**. The samples for which the sampler operator noted pollen or biological material (e.g., leaves, insects) in the sample are indicated by a yellow-colored bar. The samples for which the sampler operator noted smoke on the sample log are indicated by a rose-colored bar. Because the samples are collected over several days (7-10 days typically) and the operator is not always present, the notation of smoke being observed in the basin on the sample log report does not necessarily mean that the smoke physically impacted the sample nor that smoke did not impact the sample when the observer was not present. Thus, any conclusions regarding the impact of smoke on dry deposition samples are very tentative while the impact of pollen and other biological material actually observed in the sample are quite definitive.

The analytical results in **Figure 7-28** indicate the possibility of occasional smoke impacts and the high likelihood of biological impacts. Both of the very high nitrate results were associated with biologically impacted samples and the most of the high TKN results were also associated with biologically impacted samples. Similarly, the highest phosphorus results shown in **Figure 7-29** are almost always associated with biologically impacted samples. The biologically impacted samples are often several times greater than the temporally neighboring samples.

In addition, the year-round population of Canada geese in the Tahoe Basin has reportedly increased over the years. This increase has generated more complaints by property owners about the fouling of their property and increased speculation that these waterfowl could be an increasingly significant contributor to the nutrient load of the lake.

These natural sources of nutrients to the lake are not represented in the LTADS deposition estimates. Although these natural sources probably play a minor role in the annual deposition of nitrogen species because of other, more prodigious, sources, these natural sources could play a more significant role in the annual deposition of phosphorus due to the more limited input of P from other sources.

Figure 7-28. Nitrates and Total Kjeldahl Nitrogen Measurements associated with TRG's surrogate surface dry deposition sampler at the Ward Lake Level (Wallis Tower) site from May 1, 2002 through March 31, 2004.



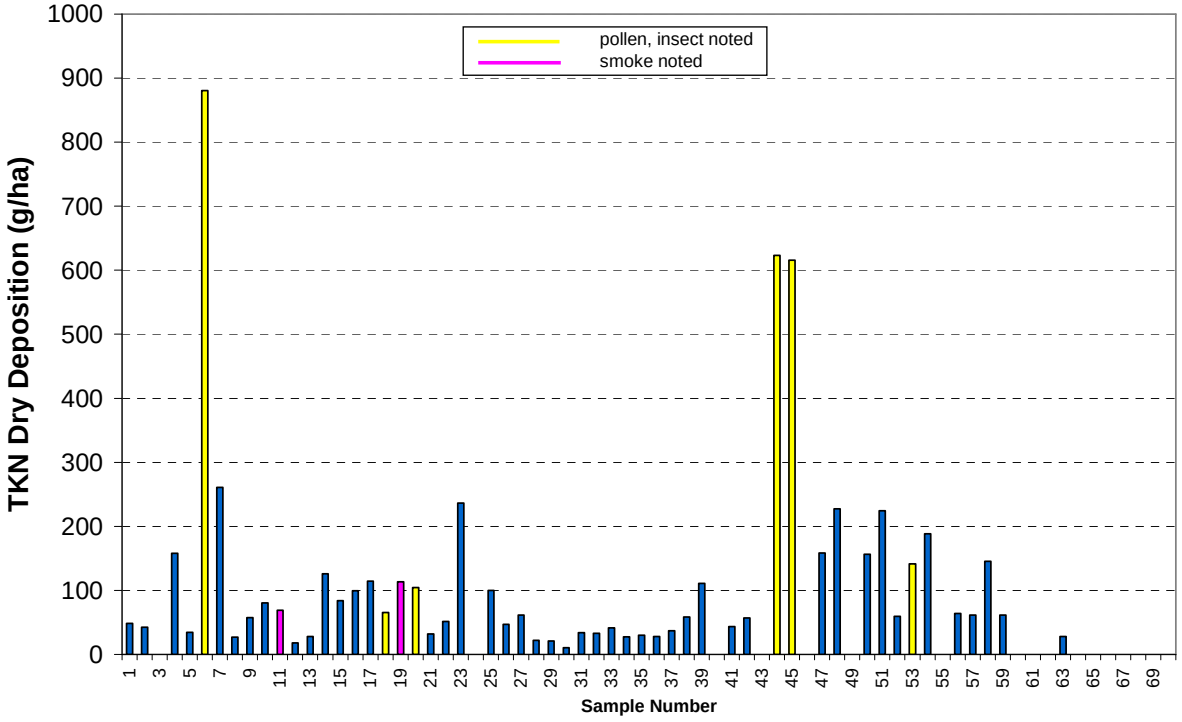
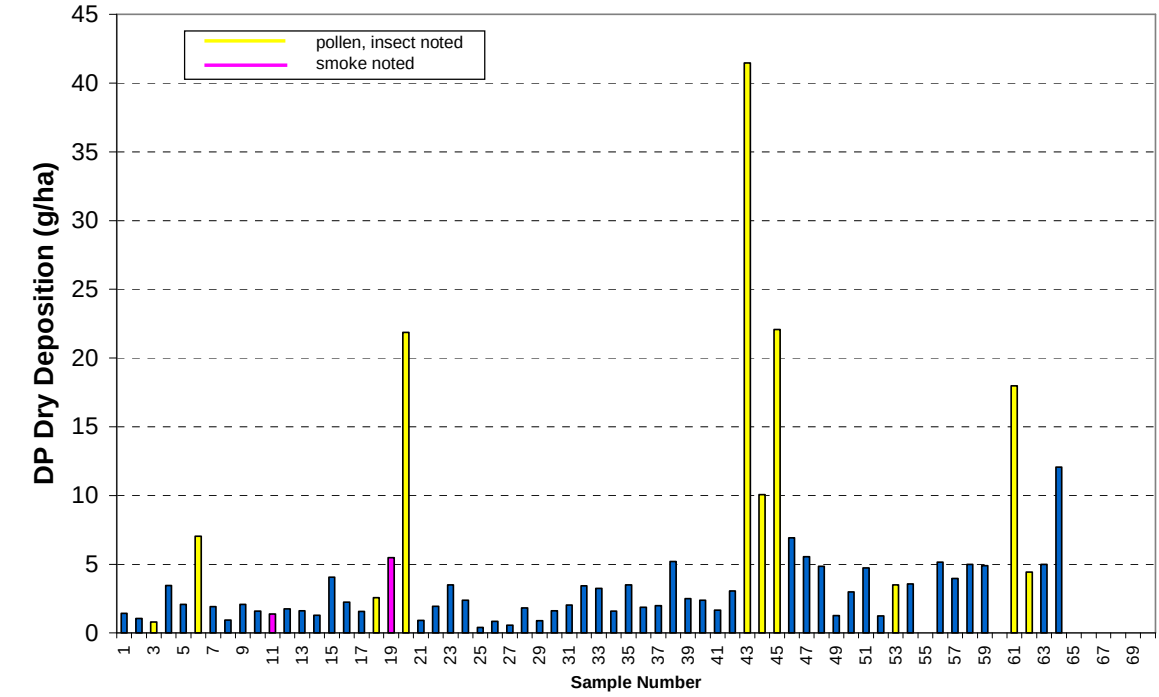
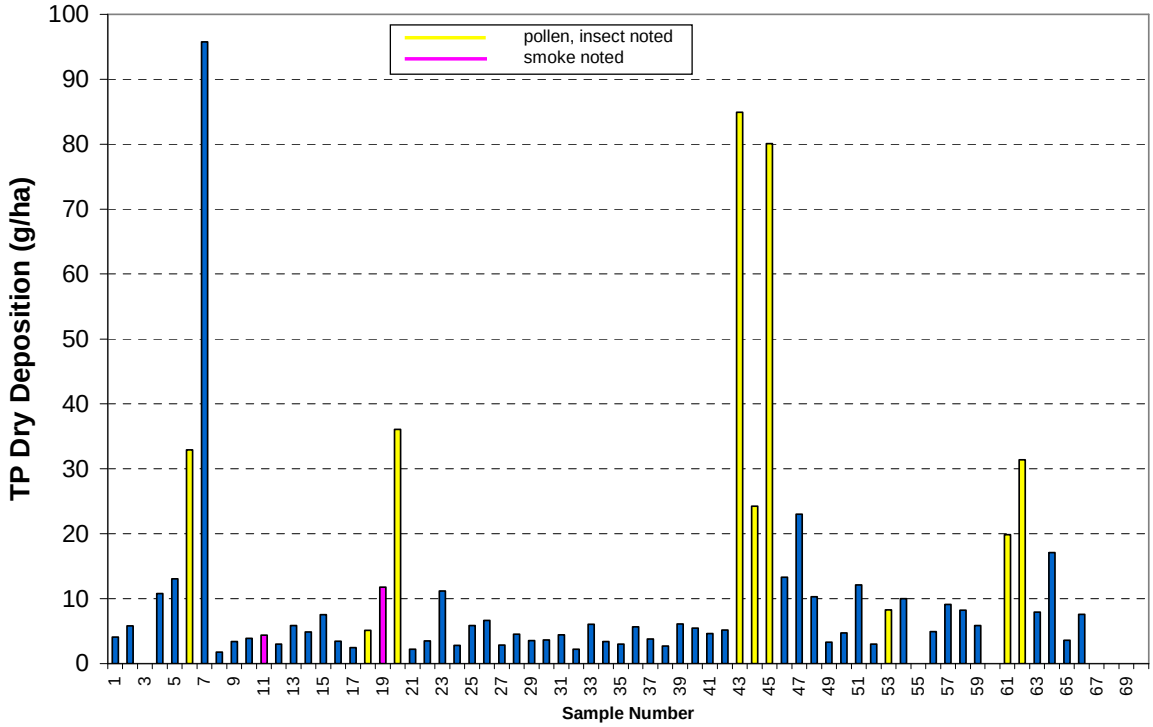


Figure 7-29. Dissolved Phosphorus and Total Phosphorus Measurements associated with TRG's surrogate surface dry deposition sampler at the Ward Lake Level (Wallis Tower) site from May 1, 2002 through March 31, 2004.





7.5 Conclusions

Multiple previous chapters in this report indicate that nitrogen is deposited to Lake Tahoe primarily in the form of ammonia gas and secondarily in the form of nitric acid. Aerosol species of nitrogen (ammonium and nitrate ions) are smaller contributors to atmospheric deposition of total nitrogen in the Tahoe Basin.

Both ambient measurements and the emission inventory suggest that local motor vehicle emissions are a source of ammonia. The inventory also indicates farming operations and residential fuel combustion as significant sources of ammonia. There is insufficient information to apportion with any certainty the ammonia between local and regional sources.

Based on observed concentrations, atmospheric lifetimes, and transport patterns we conclude that nitric acid deposited to the Lake must be primarily of local origin.

No conclusions are drawn from the LTADS ambient data about sources of phosphorus. However, the source samples collected prior to and during LTADS indicate that road dust may be the primary source with contributions from the burning of live vegetative material and lubricating oils. Surrogate surface (bucket) deposition samplers indicate that pollen may be a significant source of nutrients during the late spring and summer. Additional efforts to improve the quantification of natural sources of phosphorus, especially vegetative material and waterfowl, are warranted.

Road dust is the dominant source of PM concentrations at LTADS monitoring sites and in the immediate vicinity of the Lake, as inferred both from ambient concentrations and special source-oriented monitoring results. Road dust as the dominant source of PM is consistent with the inventory estimates of PM_coarse and PM_large provided in the current Lake Tahoe Air Basin emission inventory.

Road dust and wood smoke both appear to be important sources of fine particles. However, fine particles from these two sources likely differ in solubility and this fact may be important to consideration of their potential to impact water clarity. Insoluble particles would obviously have the potential to scatter light and to serve as a substrate for algal growth while soluble particles would not. The constituents of road dust are generally less soluble than fine particles from wood smoke or other combustion sources.

The location and timing of emissions is important to determining their potential for deposition to the Lake. Sources located near the Lake and at low altitude have much greater potential for deposition to the Lake than more distant sources. In general, emissions released during nighttime or early morning hours will have much greater potential for impacting the Lake than emissions occurring during morning through afternoon.

Thus the greatest potential for reducing deposition to the Lake would be through reducing emissions released near and immediately upwind of the Lake. Due to the

typical daily cycle of wind directions, reductions in emissions during late afternoon through mid morning would have more benefit than reducing emissions at mid-day or early afternoon. Similarly, reducing emissions that are released near ground level would be relatively more effective than reducing emissions released at altitude.

Emission inventories provide general information about the strengths of sources, but do not include source-receptor information necessary to apportion concentrations or deposition to source categories. For example, the emission inventory indicates that waste combustion is a larger source of fine particles than residential fuel combustion. However, the effective release height of these emissions (and thus their potential for contact with the lake surface) depends on the volume and temperature of the smoke. Similarly the location and timing of emissions relative to upslope and downslope winds is an important factor in determining whether there is potential for impact to the Lake.

In summary, motor vehicles exert a large influence on NOx, NH_3, PM_coarse, and PM_large concentrations in the Tahoe Basin while wood burning exerts the dominant influence on PM_fine concentrations.

7.6 References

Andronache, C, Kiang, C., Chameides, W., D. Davis, D., Anderson, B., Pueschel, R., Bandy, A., Thornton, D., Talbot, R., Kasibhatla, P. (1997) “Gas-to-particle conversion of tropospheric sulfur as estimated from observations in the western North Pacific during PEM-West B”, *J. Geophys. Res.*, **102**(D23), pp. 28511-28538.

Austin, J., and Gouze, S. (2001) *Ozone Transport: 2001 Review*, CARB Planning and Technical Support Div., Sacramento, CA, April, 2001.

Cadle, S., Mulawa, P., Hunsanger, E., Nelson, K., Rafazzi, R., Barrett, R., Gallagher, G., Lawson, D., Knapp, K., Snow, R. (1999) “Light-Duty Motor Vehicle Exhaust Particulate Matter Measurement in the Denver, Colorado, Area”, *J. Air & Waste Manage. Assoc.* **49**:PM, pp. 164-174.

Cahill, T. A. and Wakabayashi, P. (1993) “Compositional analysis of size-segregated aerosol samples”. Chapter 7 in *Measurement Challenges in Atmospheric Chemistry*. Leonard Newman, Ed., American Chemical Soc., pp. 211-228.

California Air Resources Board (CARB) (2002), Emissions Inventory CEIDARS, webpage (http://www.arb.ca.gov/ei/speciate/speciate.htm).

California Air Resources Board (CARB) (2003), *California Ambient Air Quality Data 1980-2001*, [CD-ROM PTSD-02-017-CD], http://www.arb.ca.gov/aqd/aqdcd/aqdcd.htm, CARB Planning and Technical Support Div., Sacramento, CA, December.

California Air Resources Board (CARB) (2004), Emissions Inventory Almanac, webpage (http://www.arb.ca.gov/app/emsinv/emseic1_query.php?F_DIV=-4&F_YR=2004&F_SEASON=A&SP=2005&F_AREA=AB&F_AB=LT&F_DD=Y).

California Air Resources Board (CARB) (2005), Emissions Inventory Almanac, webpage (http://www.arb.ca.gov/app/emsinv/fcemssumcat2005.php).

Chow, J.C., Watson, J.G., Kuhns, H.D., Eyemezian, V., Lownthal ,D.H., Crow, D.J., Kohl, S.D., Enelbrecht, J.P., and Green, M.C. (2004), "Source profiles for industrial, mobile, and area sources in the Big Bend Regional Aerosol Visibility and Observational (BRAVO) Study." *Chemosphere* Vol. **54**(2), pp. 185-208.

Coburn, T. (1998) "Statistical Analysis of Particulate Matter Emissions from Light-Duty and Heavy-Duty Diesel Vehicles", Final Report to The Northern Front Range Air Quality Study, U.S. Department of Energy, National Renewable Energy Laboratory, Denver.

Core, J.E., et al. (1989) "Receptor Modeling Source Profile Development for the Pacific Northwest States"; The Pacific Northwest Source Profile Library, Volume 2 - Project Final Report. State of Oregon Department of Environmental Quality, Portland, Oregon, September.

Elford, C.R. (1974) "The climate of California" in van der Leeden, F., and Troise, F.L. (Eds.), *Climates of the States*, Water Information Center, Port Washington, NY, pp. 538-594.

Fitz, D., Lents, J. (2004), "Improvement of the PM Emission Inventory for the Lake Tahoe Region." Final Report to Air Resources Board, UC Riverside College of Engineering Center for Environmental Research and Technology, April 15.

Gaffney, P. (2004), personal communication June 23, 2004, "Tahoe Ammonia for RD6_04.xls".

Gillies, J.A. Watson, J.G., Rogers, C.F., DuBois, D.W., Chow, J.C., Langston, R., and Sweet, J. (1999). "Long term efficiencies of dust suppressants to reduce PM10 emissions from unpaved roads." *Journal of the Air & Waste Management Association*, Vol. **49**(1), pp. 3-16.

Kuhns, H, Chang, M-C. O., Chow, J.C., Etyemezian, V., Chen, L-W. A. Nussbaum, N., Nathagoundenpalayam, S.K.K., Trimble, D., Kohl, S., MacLaren, M., Abu-Aliban, M., Gillies, J., and Gertler, A. (2004), "DRI Lake Tahoe Sources Characterization Study." Desert Research Institute, Final Report to Air Resources Board, October 22.

Malm, W., Sisler, J., Huffman, D., Eldred, R. and Cahill, T. (1994) "Spatial and seasonal trends in particle concentration and optical extinction in the United States", *J. Geophys. Res.* **99**(D), pp. 1,347-1,370.

Nevada Department of Environmental Protection (NDEP) Air Quality Data (http://ndep.nv.gov/baqp/trend01.htm), 2003.

Pollisar, A.V., Hopke, P.K., Malm, W.C., and Sisler, J.F. (1996) "The Ratio of Aerosol Absorption Coefficients to Sulfur Concentrations as an Indicator of Smoke from Forest Fires when Sampling in Polar Regions", *Atmos. Env*. **30**,1pp. 147-1157.

Seinfeld, J.H. (1986), *Atmospheric Chemistry and Physics of Air Pollution,* J. Wiley & Sons, p. 738.

Sisler, *et al.* (1996) *Spatial And Seasonal Patterns And Long Term Variability Of The Composition Of The Haze In The United States: An Analysis Of Data From The*

IMPROVE Network, Cooperative Institute for Research in the Atmosphere (CIRA), Colorado State University, Fort Collins, CO, ISSN: 0737-5352-32.

Turn, S., B. Jenkins, J. Chow, L. Pritchett, D. Campbell, T. Cahill, and S. Whalen, (1997) "*Elemental characterization of particulate matter emitted from biomass burning: Wind tunnel derived source profiles for herbaceous and wood fuels*", *J. Geophys. Res.*, **102**(D3), pp. 3633-3699.

van Gulijk, C., Marijnissen, J.C.M., Makkee, M. and Moulijn, J.A. (2003) "Oil-soaked sintered impactors for the ELPLI in diesel particulate measurements*." Journal of Aerosol Science*, Vol. **34**, pp. 635-640.

van Gulijk, C., Shouten, J.M., Marijnissen, J.C.M., Makkee, M. and Moulijn, J.A. (2001) "Restriction for the ELPI in diesel particulate measurements." *Journal of Aerosol Science*, Vol. **32**(9), pp. 1117-1130.

VanCuren, R., (2003) "Asian Aerosols in North America: Extracting the Chemical Composition and Mass Concentration of the Asian Continental Aerosol Plume from Long Term Aerosol Records in the Western United States", *J. Geophys. Res.*, **108**(D20), 4623, doi:10.1029/2003JD003459.

VanCuren, R., and T. Cahill (2002) "Asian aerosols in North America: Frequency and concentration of fine dust", *J. Geophys. Res.*, **107**(D24), doi:10.1029/2002JD002204, 28 December.

Watson, J.G., Fujita, E.M., Chow, J.C., Zielinska, B., Richards, L.W., Neff, W.D., and Dietrich, D. (1998), "Northern Front Range Air Quality Study." Final Report. Reno, NV, Desert Research Institute.